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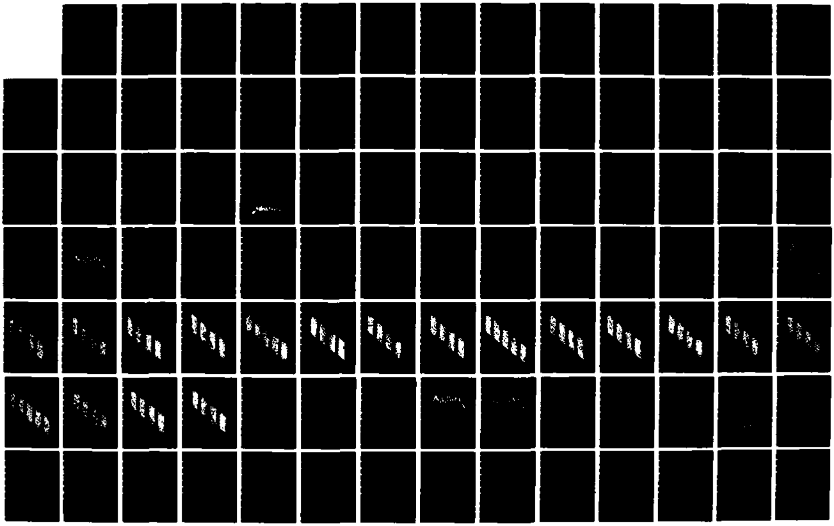

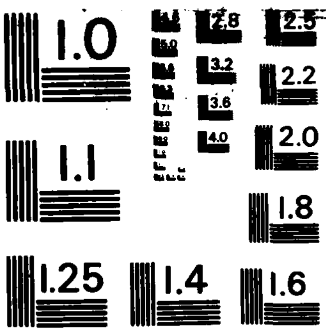

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A Comparison of Measured Take-Off and Flyover Sound Levels for Several General Aviation Propeller-Driven Aircraft

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February 1984

Final Report

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16. Abstract

The Federal Aviation Administration (FAA) is currently reviewing noise certification procedures for general aviation propeller-driven aircraft. As part of this review noise measurements were made for take-offs and flyovers of several propeller-driven aircraft at Dulles International Airport. The data from the tests were analyzed by FAA in terms of the A-weighted sound level. This analysis indicated that there were general differences between take-off and flyover sound levels.

The intent of this report is to present a review of the data without going into detailed analyses. Possible reasons for differences between take-off and flyover sound levels are explored and certain conclusions drawn. Recommendations are then made for future work in order to provide a more-detailed understanding of the physical phenomena involved.

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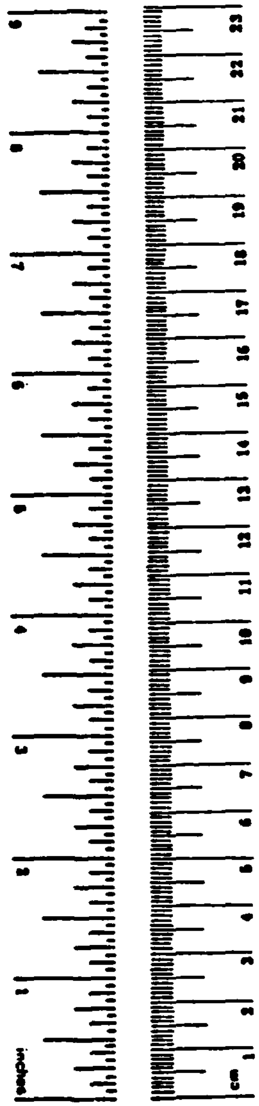
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

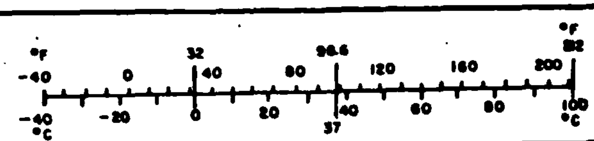
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

The Federal Aviation Administration (FAA) is currently reviewing noise certification procedures for general aviation propeller-driven aircraft. As part of this review noise measurements were made for take-offs and flyovers of several propeller-driven aircraft at Dulles International Airport. The data from the tests were analyzed by FAA in terms of the A-weighted sound level. This analysis indicated that there were general differences between take-off and flyover sound levels, although the reasons for the differences were not identified.

Data from these FAA noise tests have now been analyzed in greater detail in order to explore possible explanations for the differences in sound level. The analysis has considered sample take-off and flyover test runs for eight of the aircraft included in the FAA tests. Tape recordings of the sound levels were analyzed in terms of time histories, sequential spectra and spectra associated with the peak A-weighted sound levels. It was intended originally to analyze data for nine aircraft but the Cessna 170 and Cessna 180 were excluded because of unavailability of the data for both sets of test conditions. Measurements for the Cessna 210 were included instead. The other aircraft considered were the Beech B58P, Beech B200, Cessna 414, Cessna 425, Piper PA-28, Piper PA-38, and Piper PA-42.

Initial plans also called for the analysis of two data samples for take-off conditions and two samples for flyovers at flight conditions similar to those associated with take-off. As the analysis proceeded, it was apparent that additional flyover conditions had to be considered.

The analysis generated a large amount of data which are presented in this report as a series of appendices. The data will thus be available for any subsequent analysis as well as providing supporting evidence for the present discussion.

The intent of the discussion is to present a review of the data without going into detailed analyses. Possible reasons for differences between take-off and flyover sound levels are explored and certain conclusions drawn. Recommendations are then made for future work in order to provide a more-detailed understanding of the physical phenomena involved.

2.0 TEST MEASUREMENTS

Analog data tapes were provided by FAA for tests on eight general aviation propeller-driven aircraft. The aircraft, and the associated dates of the tests, were

Aircraft	Test Date
Beech B58P Baron	9/28/82
Beech B200 Super King Air	8/31/82
Cessna 210 Centurion	6/28/83
Cessna 414 Chancellor	9/14/83
Cessna 425 Conquest 1	10/26/82
Piper PA-28RT-201T Turbo Arrow IV	7/13/82 (Take-off)
	7/20/82 (Flyover)
Piper PA-38-112 Tomahawk	8/10/82
Piper PA-42 Cheyenne	9/08/82

In all cases except the Cessna 210, the measurements were performed during the later summer of 1982. The Cessna 210 tests were conducted in 1983 in order to obtain additional data.

Relevant characteristics of the test airplanes are given in Table 1. There were three single-engined and five twin-engined airplanes. Five aircraft had reciprocating engines and three had turboprops. It will be noted that, for the piston-engined aircraft, 3-bladed propellers were fitted to 6-cylinder engines and a 2-bladed propeller to a 4-cylinder engine. Consequently, the propeller blade passage frequency and the engine firing frequency are identical in all cases, since the engines are not geared. The propellers have variable pitch with the exception of the 2-bladed propeller of the PA-38.

TABLE 1

TEST AIRPLANE CHARACTERISTICS

AIRPLANE MODEL	Engines			Propeller		
	Type	Number	No.of Cylinders	No. of Blades	Diameter (Inches)	Pitch
Beech B58P Baron	Recipr.	2	6	3	78	Variable
Beech B200 Super King Air	Turboprop	2	-	3	98.5	Variable
Cessna 210 Centurion	Recipr.	1	6	3	80	Variable
Cessna 414 Chancellor	Recipr.	2	6	3	76.5	Variable
Cessna 425 Conquest 1	Turboprop	2	-	3	93.4	Variable
Piper PA-28RT-201 TurboArrow IV	Recipr.	1	6	3	76	Variable
Piper PA-38-112 Tomahawk	Recipr.	1	4	2	72	Fixed
Piper PA-42 Cheyenne	Turboprop	2	-	3	95	Variable

For the purposes of the tests a reference ground track was defined by FAA as a line parallel to and 50 feet west of the edge of Runway 36 at Dulles. The tests could be performed with either a north or south traffic flow. A plan of the test site is shown in Figure 1. In the case of a northbound traffic flow it was necessary to use a simulated take-off procedure. A full-stop take-off procedure was utilized for southbound traffic flow. The data tapes provided by FAA for 1982 tests were associated with Site #2 except for the Cessna 414 where the data were associated with Site #1. Cessna 210 tapes (1983 FAA tests) were recorded at a location equivalent to 8200 feet from the start of take-off roll.

The test runs, and associated flight conditions, selected for the present data analysis are listed in Table 2. As a minimum, two take-off and two flyover runs were taken from the larger set of data runs provided by FAA. The initial choice of the flyover runs was predicated on the assumption that the take-off and flyover flight conditions should be associated with similar values for the propeller tip helical Mach number. As the analysis developed, it was decided that take-off and flyover data should also be compared on the basis of similar values of propeller tip rotational Mach number (or propeller rpm). Additional flyover runs were selected in order to make this comparison. Also, in the case of the Cessna 210, take-off noise measurements were included in the data analysis to cover the range of test airspeeds.

Propeller tip Mach numbers, helical and rotational, associated with the test data discussed in this report are shown in Figure 2. The range of Mach numbers shown for any given airplane does not cover the full range tested by FAA; it is restricted to values at flyover which are similar to those for take-off. However, the figure does show that the variation in tip Mach number from airplane to airplane is quite large.

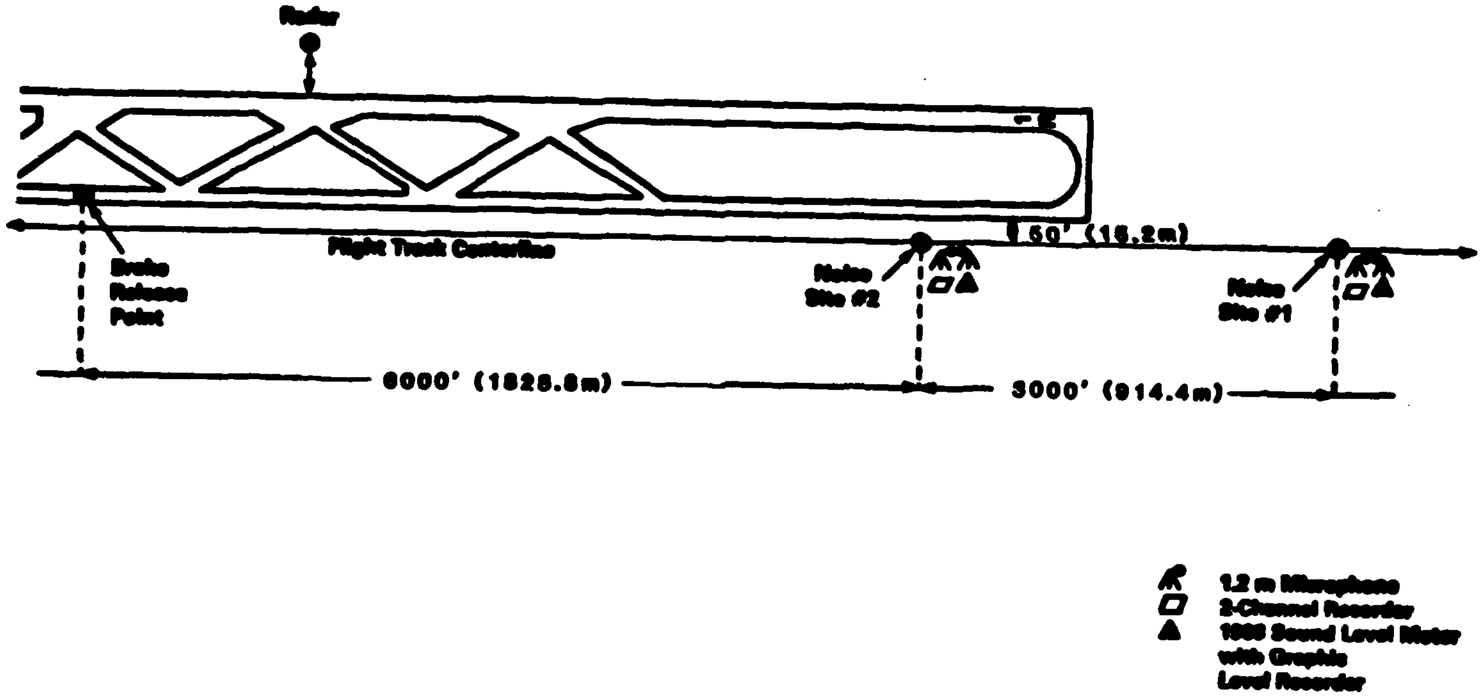


FIGURE 1. LOCATION OF MEASUREMENT POSITIONS

TABLE 2

TEST CONDITIONS OF RUNS SELECTED FOR ANALYSIS

Run #	Condition	Altitude (ft)	IAS (kts)	Propeller rpm	Power	Torque	M*	M*
Beech B58P								
2	Take-off	496	115	2700	—	—	0.821	0.840
6	Take-off	513	115	2700	—	—	0.821	0.840
9	Flyover	564	158	2700	67%	—	0.821	0.857
10	Flyover	597	160	2650	67%	—	0.805	0.844
18	Flyover	570	160	2700	67%	—	0.821	0.858
19	Flyover	546	194	2600	97%	—	0.790	0.846
26	Flyover	699	176	2600	75%	—	0.790	0.836
Beech B200								
2	Take-off	665	126	2000	—	2230	0.765	0.789
3	Take-off	693	126	2000	—	2230	0.765	0.789
11	Flyover	578	232	1850	85%	2050	0.707	0.789
12	Flyover	597	232	1900	85%	1995	0.727	0.806
14	Flyover	506	234	2000	85%	1895	0.765	0.842
22	Flyover	543	214	1900	71%	1672	0.727	0.795
Cessna 210								
A2	Take-off	640**	103	2880	98%	—	0.881	0.896
A3	Take-off	640	103	2880	98%	—	0.881	0.896
C5	Take-off	640	84	2880	95%	—	0.881	0.892
F11	Take-off	640	133	2880	98%	—	0.881	0.905
G18	Flyover	640	149	2880	98%	—	0.881	0.910
G20	Flyover	640	149	2880	98%	—	0.881	0.910
I26	Flyover	640	135	2830	84%	—	0.866	0.891
Cessna 414								
2	Flyover	498	176	2650	89%	—	0.775	0.829
3	Flyover	564	176	2600	89%	—	0.760	0.815
19	Flyover	479	147	2700	89%	—	0.789	0.830
23	Take-off	893	110	2700	—	—	0.789	0.818
24	Take-off	876	110	2700	—	—	0.789	0.818

* M_r = propeller tip rotational Mach number, M_h = tip helical Mach number

** 640 ± 20%

TABLE 2
(Cont'd)
TEST CONDITIONS OF RUNS SELECTED FOR ANALYSIS

Run #	Condition	Altitude (ft)	IAS (kts)	Propeller rpm	Power	Torque	M_r^*	M_h^*
Cessna 425								
3	Take-off	1349	115	1900	—	1244	0.700	0.722
4	Take-off	1424	116	1900	—	1244	0.700	0.722
10	Flyover	481	200	1750	90%	—	0.644	0.711
11	Flyover	462	205	1750	90%	—	0.644	0.714
12	Flyover	462	200	1850	90%	—	0.681	0.744
18	Flyover	453	170	1900	50%	—	0.700	0.744
Piper PA-28								
3	Take-off	738	97	2575	—	—	0.756	0.771
15	Take-off	547	99	2575	—	—	0.756	0.766
6.1	Flyover	501	138	2575	75%	—	0.756	0.784
6.4	Flyover	481	142	2500	75%	—	0.734	0.764
6.5	Flyover	481	141	2500	75%	—	0.734	0.764
Piper PA-38								
5	Take-off	708	70	2350	—	—	0.649	0.658
6	Take-off	674	69	2350	—	—	0.649	0.658
18	Flyover	551	95	2350	70%	—	0.649	0.661
21	Flyover	580	90	2300	65%	—	0.636	0.647
Piper PA-42								
1	Flyover	555	240	2000	100%	1895	0.736	0.821
9	Flyover	566	231	1850	100%	2050	0.681	0.766
17	Flyover	592	205	1900	75%	1493	0.699	0.765
20	Flyover	521	183	1900	50%	995	0.699	0.753
23	Take-off	1293	115	2000	—	1895	0.736	0.755
25	Take-off	1337	115	2000	—	1895	0.736	0.755

* M_r = propeller tip rotational Mach number, M_h = tip helical Mach number

** 640 ± 20%

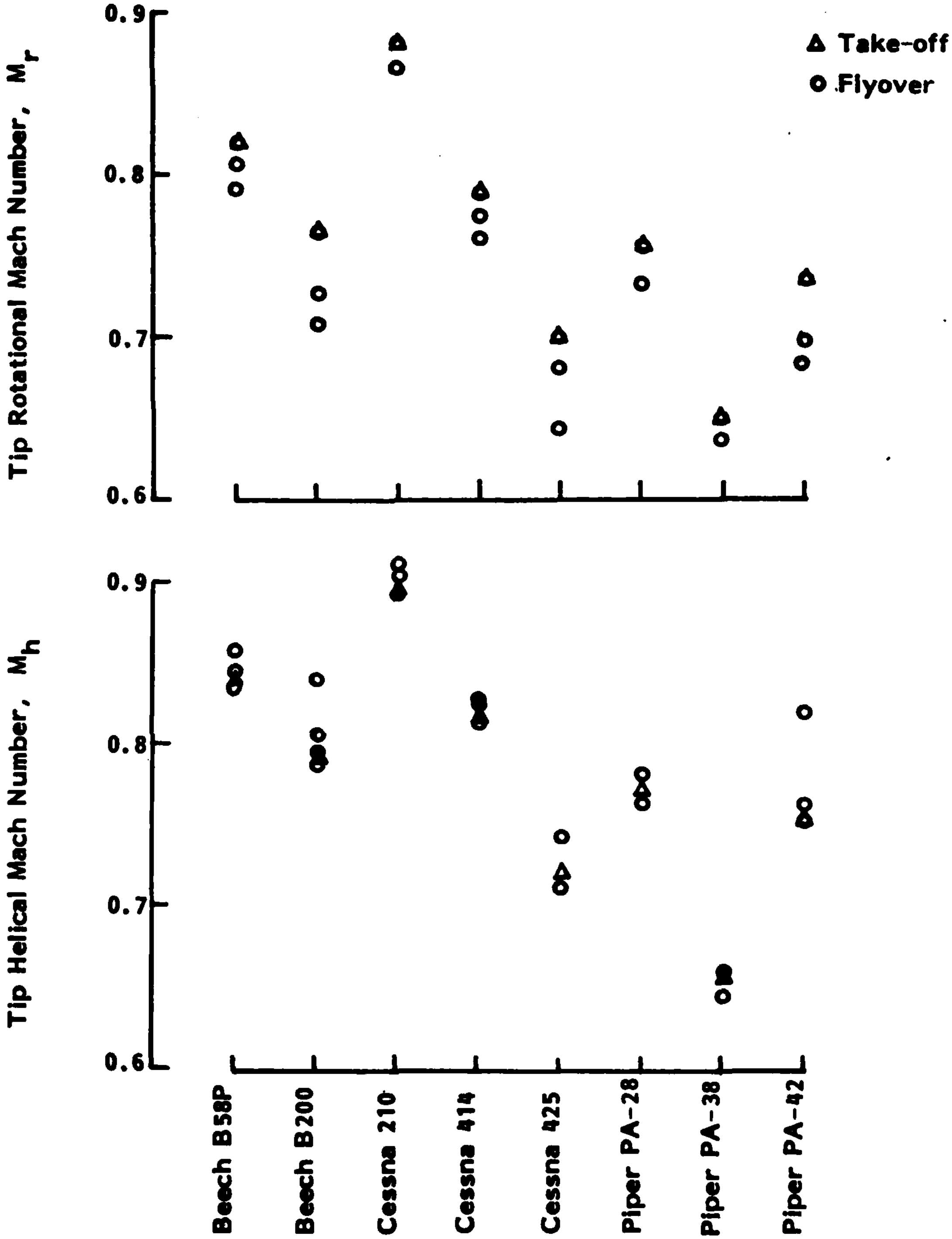


FIGURE 2. RANGE OF PROPELLER TIP ROTATIONAL AND HELICAL MACH NUMBERS FOR TESTS ANALYZED

In all cases, the sound levels were measured using a microphone located 4 feet above the ground surface. However, additional measurements were made for the Cessna 210 with a second microphone located at the ground plane. Data for the two microphone locations were recorded simultaneously for the Cessna 210 tests. The acoustic data were recorded by FAA on analog tapes by means of Nagra IV-SJ tape recorders. The data were replayed by BBN using similar tape recorders. The analyzer equipment used to reduce the data are identified in the appropriate appendices of this report.

3.0 DATA ANALYSIS

3.1 General Approach

The approach of the data analysis was to perform narrowband spectra and other data reduction procedures, so that any differences between take-off and flyover sound levels could be identified. Since the noise certification process involves the use of A-weighted sound levels, all the data discussed in this report are presented in terms of A-weighted sound levels, irrespective of whether the results are broadband or narrowband.

The data analysis was performed first in terms of the A-weighted sound level time histories. These are shown in Appendix B for the test conditions investigated. The time histories were used to determine the time of peak sound level for subsequent narrowband analysis. Narrowband spectra associated with the peak A-weighted sound level are also shown in Appendix B, the spectra being plotted for the frequency range 0 to 2000 Hz. Other narrowband spectra for the ground-plane microphone used in the Cessna 210 tests are presented in Appendix C.

Inspection of the narrowband spectra shows the presence of discrete frequency components at harmonics of the blade passage frequency and the cylinder firing frequency (when the airplane had reciprocating engines). The spectra also show the presence of spectral troughs associated with destructive interference between the direct acoustic signal at the microphone and the signal reflected from the ground surface, when a microphone height of 4 feet was used.

A qualitative representation of the time histories of the harmonic components can be obtained from a sequential spectra presentation whereby narrowband spectra are computed for a sequence of closely-spaced time increments. Spectra of this type are presented in Appendix A.

One disadvantage of the narrowband spectra presented in Appendix B is that it is difficult to estimate the contributions from broadband noise components. This estimate can be better made when spectral analysis is performed in one-third octave bands; these spectra are plotted in Appendix E.

3.2 Time Histories

The measured time histories for the A-weighted sound levels show a range of shapes, as can be seen from the examples in Figure 3. In some cases, such as in Figure 3(a), the sound level varies rapidly with time in the neighborhood of the peak value whereas in other cases, such as in Figure 3(c), there is a relatively slow variation with time. The time scales shown on the plots have arbitrary starting values and are used solely to show the rate of change of the sound levels. No attempt was made to determine the time at which the airplane was overhead.

Several factors affect the characteristics of the time histories. These factors include airplane altitude and speed, and the directivity of the sound sources. Thus, the sharply peaked time history in Figure 3(a) is associated with an airplane speed of 194 kts and an altitude of 546 ft whereas the broad-peaked time history in Figure 3(c) represents a slower flight speed (116 kts) at a higher altitude (1424 ft). The intermediate pattern for the time history in Figure 3(b) is associated with a flight speed similar to that for Figure 3(c) and an altitude similar to that for Figure 3(a).

In general the sound level measurements for take-off conditions are associated with lower aircraft flight speeds and higher altitudes than are the measurements for flyovers. Consequently the take-off time histories show a more gradual change of sound level with time than do the flyover time histories. When the sound levels change rapidly with time, the integrating time of

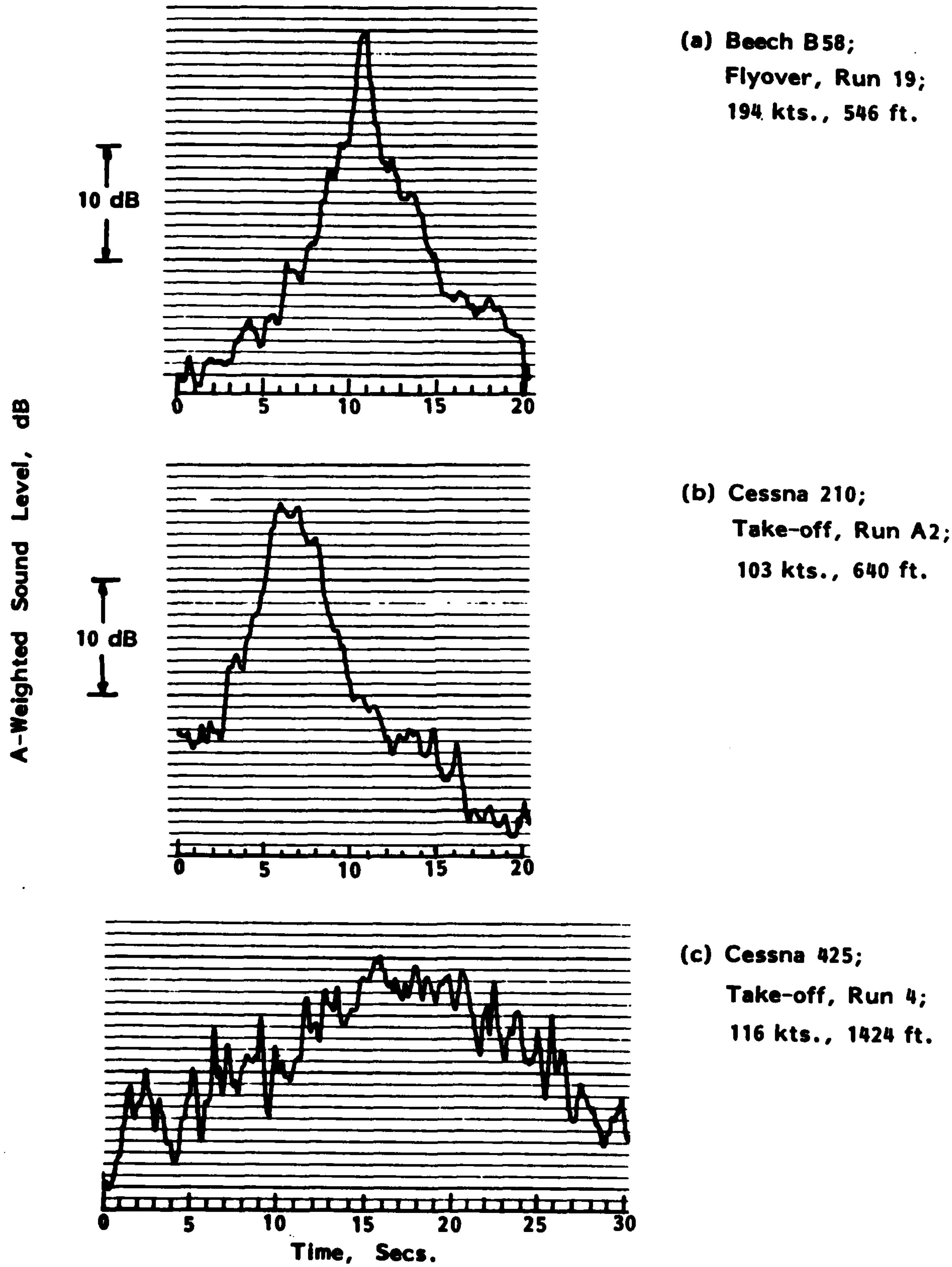


FIGURE 3. SAMPLE TIME HISTORIES FOR A-WEIGHTED SOUND LEVELS

the measuring equipment can have a significant effect on the indicated value. Certification procedures impose certain restrictions on integrating time and meter response when measuring the overall A-weighted sound level. No such restrictions were imposed in this investigation since the intent was to gain an insight into the physical phenomena.

3.3 Narrowband Spectra

All the narrowband sound level spectra anlayzed in this study show the presence of discrete frequency components at harmonics of the blade passage frequency. However, the relative magnitudes of the components vary from airplane to airplane and from test condition to test condition. In the case of aircraft with turboprop engines, the spectral components at frequencies which are multiples of the propeller blade passage frequency can be attributed, with confidence, to propeller noise. The situation is not so clearly defined for aircraft with reciprocating engines since the propeller blade passage frequency and the engine firing frequency are identical. However, in most cases the spectral components at multiples of the cylinder firing frequency are usually significantly lower than those at the propeller harmonics. Thus, it is assumed that the strong peaks in the spectra are generally associated with propeller noise rather than engine exhaust noise.

Discrete frequency components attributable to propeller noise are most evident in spectra of the Cessna 210 (see Figure 4(a)). In this case the propeller rotational speed was much higher than planned (2880 rpm instead of 2700 rpm) because of a tachometer error. Consequently the propeller tip Mach numbers are significantly higher than those for the other test aircraft, as can be seen in Figure 2. The spectrum in Figure 4(a) is associated with a tip helical Mach number, M_h, of 0.905 and a rotational Mach number, M_r, of 0.881.

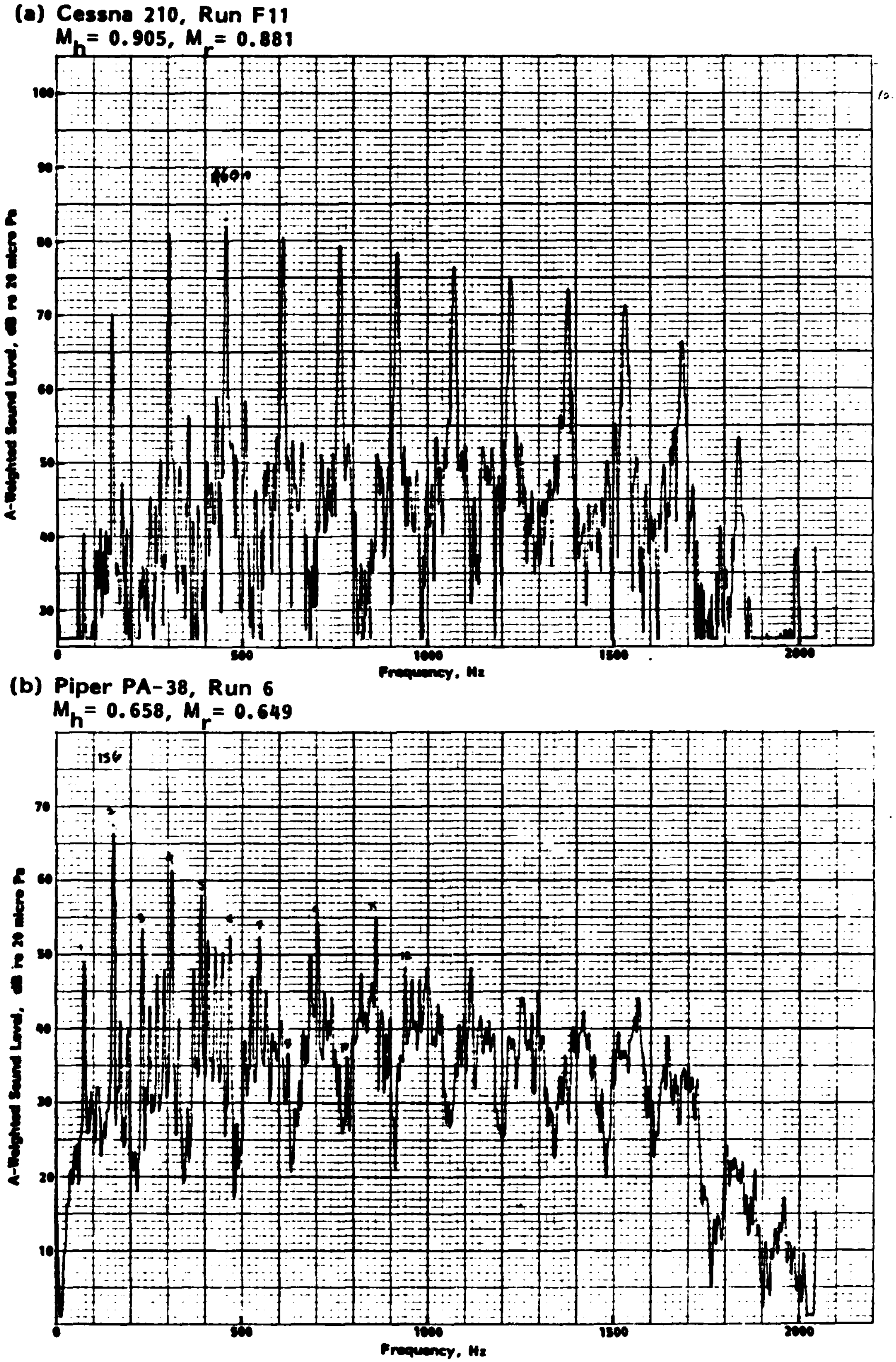


FIGURE 4. NARROWBAND A-WEIGHTED SOUND LEVEL SPECTRA FOR AIRCRAFT WITH HIGH AND LOW PROPELLER TIP MACH NUMBERS

Propeller noise is least evident in the sound level spectra for the PA-38 (Figure 4(b)), which has, for the test aircraft, the lowest Mach number for the propeller tip (M_h = 0.658, M_r = 0.649). In this case it is quite likely that the spectral components at multiples of the blade passage frequency may contain significant contributions from exhaust noise. Spectral components at multiples of the individual cylinder firing frequency can be readily identified in Figure 4(b), and the associated sound levels are similar in magnitude to those at the harmonics of the blade passage and engine firing frequency. The individual cylinder firing frequency in this case is one-quarter of the blade passage frequency.

The narrowband spectra presented in Appendix B represent only a small time slice from the total take-off or flyover run. The sequential spectra shown in Appendix A were used to establish that the general spectral characteristics existed at other time slices in the run. Thus, spectra which show a strong harmonic content at the time of peak A-weighted sound level also show strong harmonic content for time intervals of ± 3 seconds about the time of maximum sound level. For example, Figures A.6 and A.7 show the presence of several harmonics over the six-second time period. In other cases, such as the flyover of the Beech 200, Run 12 (Figure A.4), the sequential spectra show little evidence of harmonic content; these spectra generally appear to be random in content.

Differences between take-off and flyover noise spectra are easily seen in the sequential presentation. Data for the Piper PA-42 Cheyenne can be used as an example. The take-off results in Figure A.17 show a strong harmonic content throughout the six-second time sample. In contrast, the corresponding spectra for a flyover at approximately the same propeller tip helical Mach number show a random character over much of the

frequency range of interest (Figure A.18). When a flyover run condition is selected such that the propeller rpm is the same as that at take-off, the harmonic content becomes more pronounced, but the pattern is still not as distinct as at take-off.

3.4 One-Third Octave Band Spectra

The narrowband spectra presented in Appendices B and C were restricted to the frequency range 0 to 2000 Hz since interest was centered on the narrowband contributions from the propeller. However, a complete assessment of the overall A-weighted sound levels cannot be made without an evaluation of the sound level spectra over a wider frequency range. This was achieved by means of one-third octave band data reduction in the frequency range to 63 to 10,000 Hz. The resulting spectra are contained in Appendix E.

The one-third octave band analysis was performed with a 0.5 sec integration time. The intent was to obtain spectrum levels corresponding to the maximum A-weighted sound level, as was the case for the narrowband analysis. However, the one-third octave band and narrowband analyses were not performed simultaneously so that there may be some small differences between the actual sample times used in the two cases.

Discussion of the one-third octave band spectra should consider take-off and flyover sound levels separately. In the case of take-off, the spectra are dominated by bands containing components at harmonics of the blade passage frequency. When the contributions from propeller noise are summed, the A-weighted sound levels are generally within 1 dB of the overall level, except for the Piper PA-38. In that case the difference is about 3 dB.

The situation for flyover sound levels depends on the propeller rpm for the test condition. The difference between the summed contributions for the propeller and the overall level ranges from less than 1 dB to about 6 dB, with the highest differences again being associated with the PA-38. The higher the propeller rpm, the lower the difference between the propeller contributions and the overall level.

This assessment of the contributions from propeller noise is somewhat approximate because it relies on a judgment based on inspection of the narrowband spectra. However, the general conclusion is that an analysis of the spectral components at harmonics of the blade passage frequency will usually provide a reasonably good indication of the overall A-weighted sound level trends.

4.0 REFLECTIONS FROM GROUND SURFACE

When a microphone is located above the ground surface it will record acoustic signals which travel directly from the source and other signals which are reflected from the ground. Superposition of the two signals will result in constructive and destructive interference throughout the frequency spectrum. A detailed analysis of the effect of reflected signals on the take-off and flyover sound levels would require a knowledge of the ground impedance at the measurement site. However, such an analysis is outside the scope of the present study which is concerned with general evaluations only. Thus the following analysis will assume for simplicity, that the ground surface is a perfectly-reflecting plane.

With the exception of the ground surface microphone used in the Cessna 210 tests, the microphone height was 1.22 m (4 feet) above the ground plane. Thus, when the sound is incident at 90° to the horizontal (i.e., the source is directly overhead) the destructive interference effects will be greatest at 70 Hz and odd multiples thereof (210, 350, 490, ... Hz). Constructive interference will be a maximum at even multiples of 70 Hz (i.e., 140, 280, 420, ... Hz). If the maximum value of the A-weighted sound level is associated with source emission when the airplane is not overhead, the maximum effects of destructive and constructive interference will occur at higher frequencies. For example, if the emission angle is 70° to the horizontal, maximum destructive interference will occur at frequencies which are odd multiples of 74.5 Hz.

Inspection of the narrowband spectra in Appendix B provides strong evidence of destructive interference, although the effects are masked to some extent by the basic shape of the spectra. Spectral troughs caused by destructive interference can be seen, for example, in the data for a Cessna 414 flyover

(Run 3) which is reproduced in Figure 5(a). The trough at about 72.5 Hz is not very obvious, but subsequent troughs at about 217.5, 362.5, 507.5, 652.5 Hz etc. are easily seen.

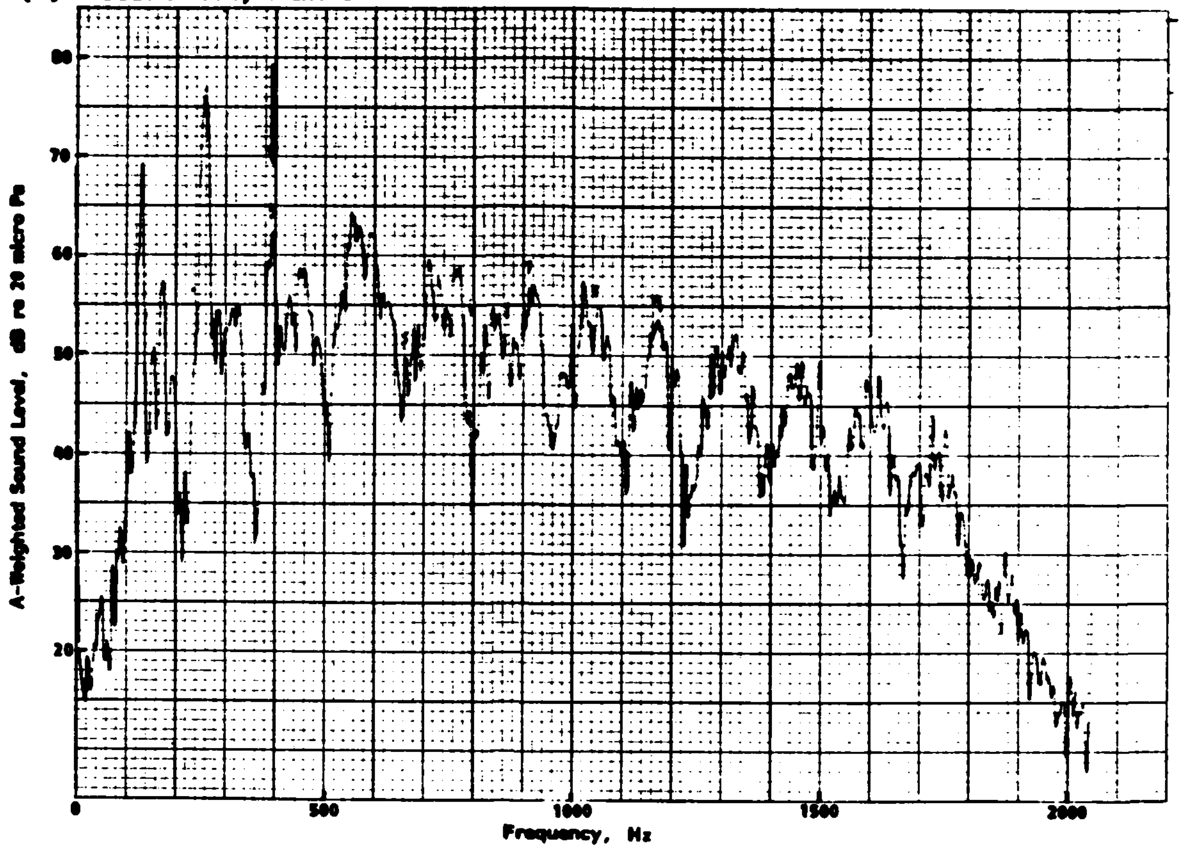
Figures 5(a) and 5(b) also show the influence of destructive interference on spectral peaks at harmonics of the blade passage frequency. In Figure 5(a), the third harmonic occurs at a frequency of about 395 Hz which is fairly close to the destructive interference trough at 362.5 Hz. Thus the level of the third harmonic is quite low. The effect is seen more strongly in Figure 5(b) which contains a narrowband spectrum for the Beech B200. For this case the second harmonic occurs at 208 Hz which is very close to the destructive interference trough at 213 Hz. As a consequence, the level of the second harmonic is about 15 dB lower than the levels of the adjacent first and third order harmonics. A similar effect, but smaller in magnitude, is seen at the fifth order harmonic (520 Hz) which is close to the destructive interference trough at 497 Hz.

These reductions in harmonic level due to destructive interference become obvious when the harmonic spectrum levels are plotted, as in Appendix D. For example, Figure D.2, which contains data for the B200 shows marked reductions in sound level for harmonics of order 2 and 5. Other figures in the appendix show similar effects.

Augmentation of the spectral levels due to constructive interference cannot be readily identified because the variation with frequency is much more gradual than is the case for destructive interference. The irregular shape of the spectra mask this gradual augmentation pattern.

The sequential spectra in Appendix A also show evidence of destructive interference. This is marked by the rapid disappearance and reappearance of a harmonic component as time

(a) Cessna 414, Run 3



(b) Beech B200, Run 3

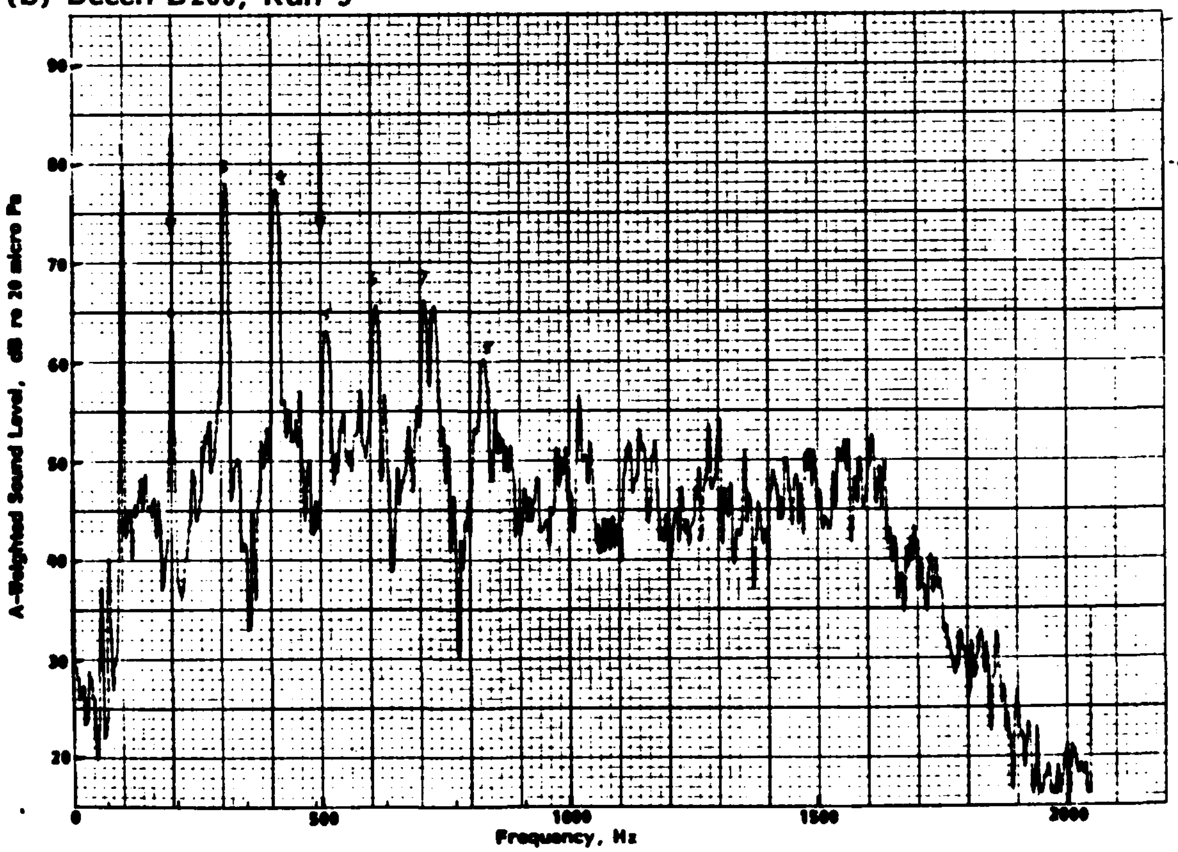


FIGURE 5. EFFECTS OF DESTRUCTIVE INTERFERENCE CAUSED BY SOUND REFLECTION FROM GROUND SURFACE

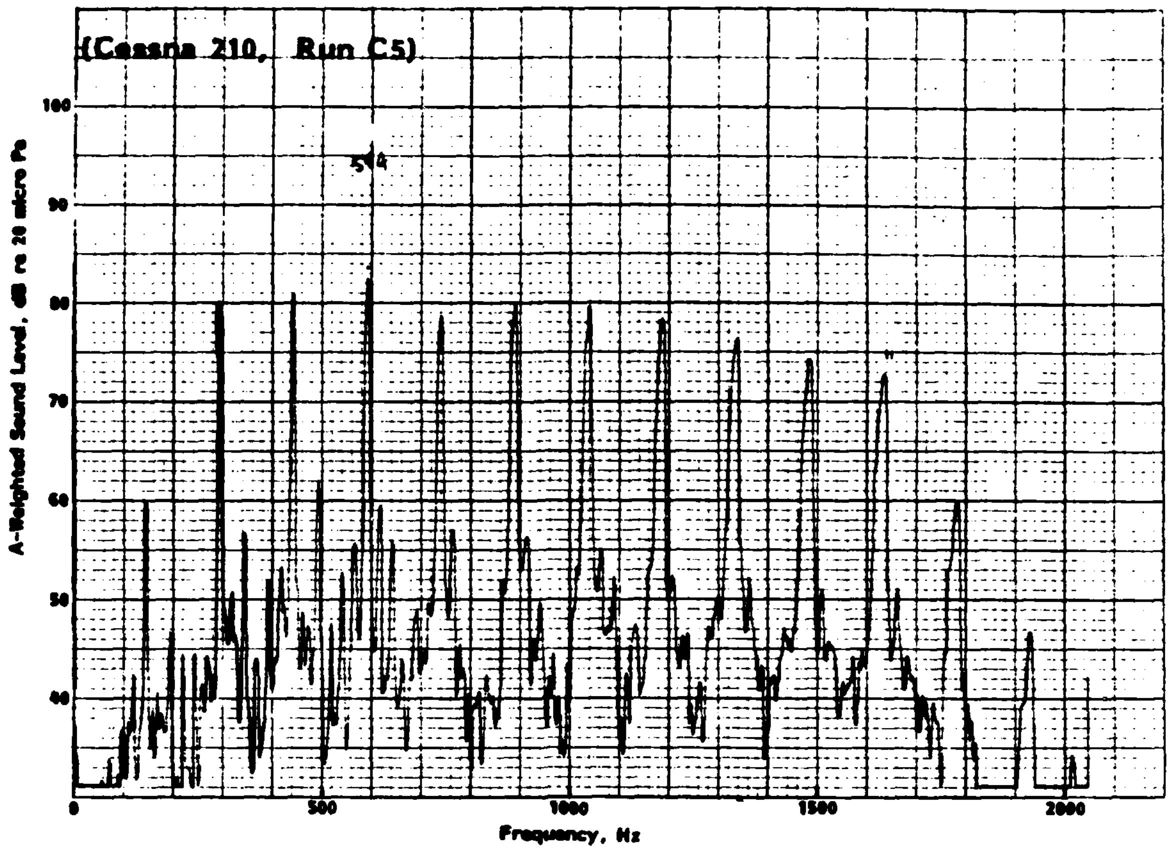
varies. Two factors are responsible -- the effect of the variation in angle of propagation as the airplane flies over the microphone, and the Doppler shift of the harmonic frequencies.

Data measured by FAA for the Cessna 210 provide an opportunity to compare sound levels measured in the ground plane with corresponding levels four feet above the ground. Spectra for Run C5 are shown in Figure 6. As expected the destructive interference troughs which, for a microphone height of 4 feet, occur at intervals of 145 Hz in Figure 6(a) are not seen in the ground-plane spectrum (Figure 6(b)). Because of this, the harmonic components at multiples of the cylinder firing frequency are much more evident in the spectrum measured at ground level.

Destructive interference is not observed at harmonics of the blade passage frequency for the Cessna 210. This is because the harmonics lie almost midway between adjacent destructive interference troughs for the particular choice of a 4-foot high microphone. If another height were selected, the pattern would be different. The data do show, however, that the measured sound levels of the harmonics are higher in the ground plane than at the 4-foot high microphone. This is shown in the summary plot in Figure 7, which presents the difference between the sound levels at the two microphone position.

First, the data show a variation of about ± 4 dB in the difference for any given harmonic order. This is not surprising in view of the short sample lengths used in the data reduction. Secondly, the mean value of the difference is positive except for the fundamental, indicating that the levels are higher at the ground than at the four-foot height. This result depends on microphone height and the value of the blade passage frequency. The average difference for harmonics 2 through 6 is 4 dB; it is higher at higher order harmonics. These differences seem to be fairly large considering that the harmonic frequencies are

(a) Microphone Height = 4 feet



(b) Microphone Height = 0 feet

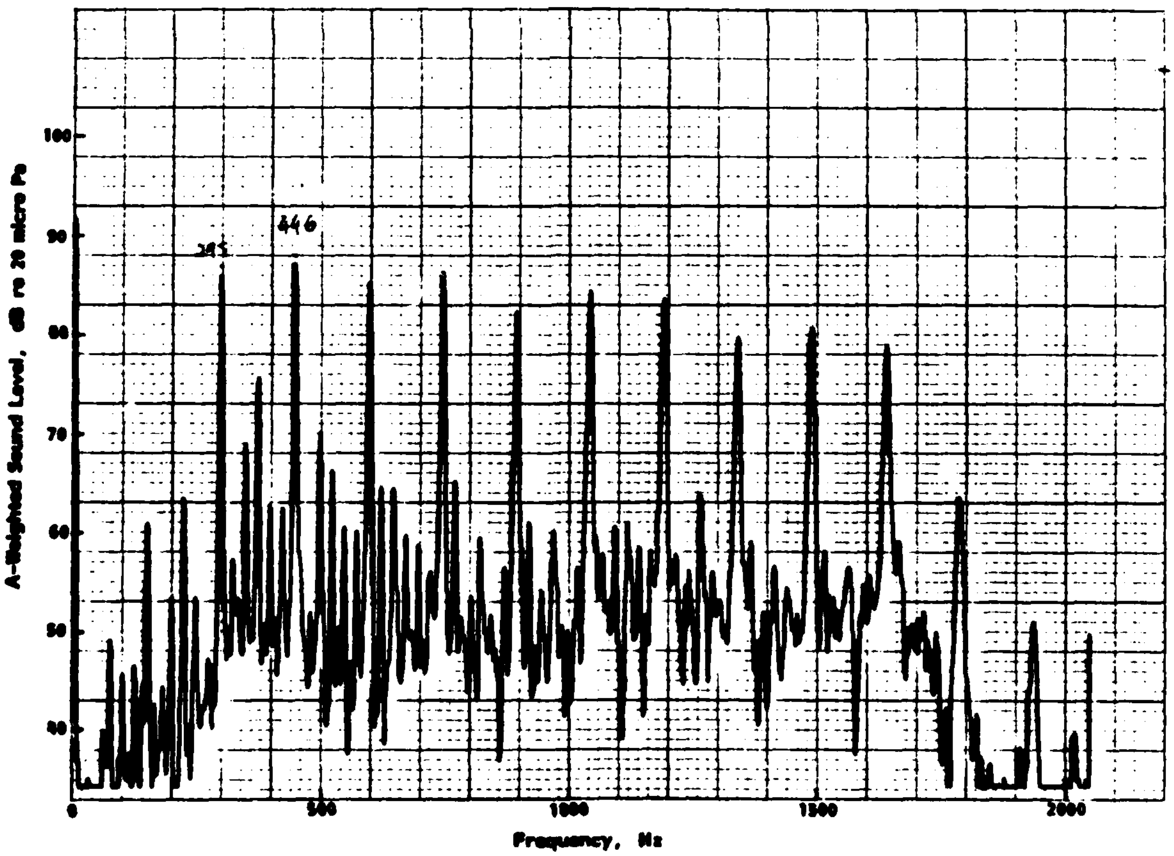


FIGURE 6. COMPARISON OF NARROWBAND SPECTRA MEASURED FOUR FEET ABOVE GROUND LEVEL AND IN THE GROUND PLANE

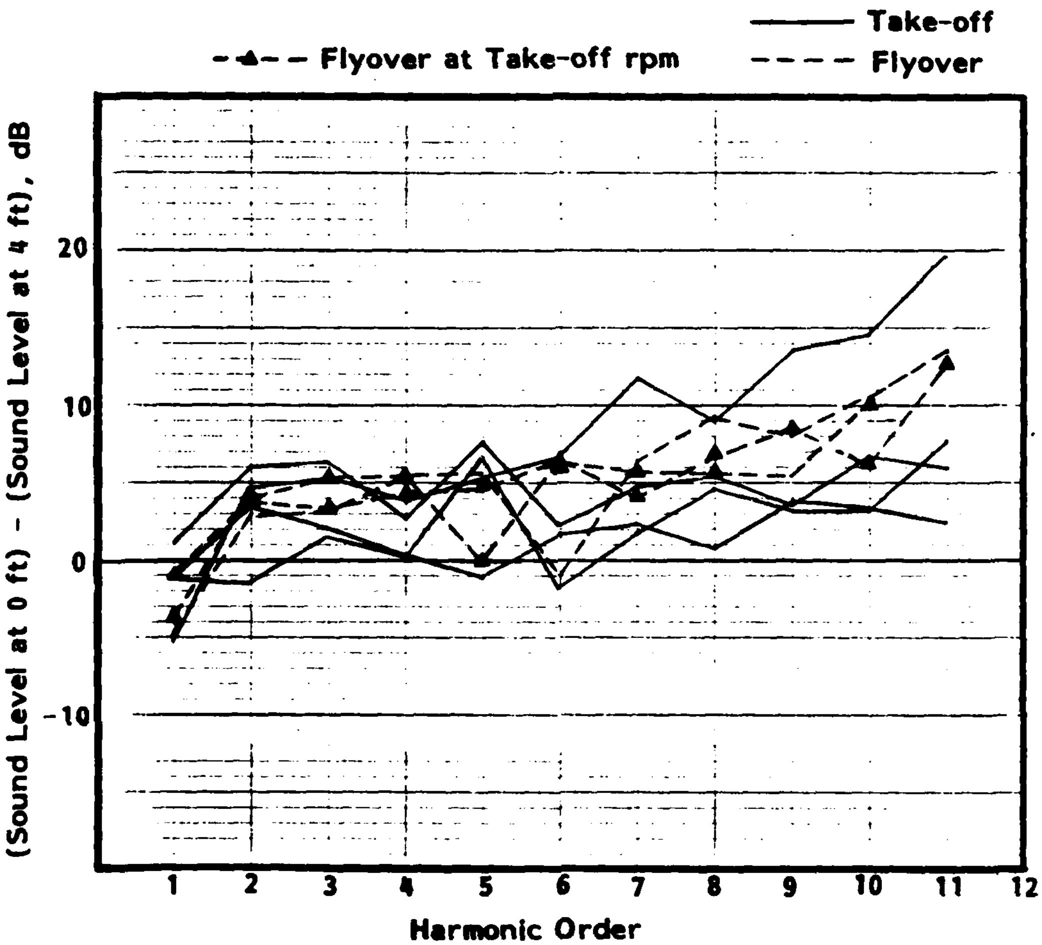


FIGURE 7. DIFFERENCE BETWEEN PROPELLER HARMONIC SOUND LEVELS MEASURED ON GROUND PLANE AND FOUR FEET ABOVE THE GROUND (CESSNA 210)

almost centrally located between the frequencies of the destructive interference troughs. Further investigation would seem to be necessary if microphone height becomes an important issue in noise certification. One factor for consideration is the difference in the acoustic impedance of the ground at the surface microphone and the ground at the point at which sound is reflected to the 4-foot high microphone.

5.0 DIRECTIVITY EFFECTS

Analysis of the narrowband spectra associated with maximum A-weighted sound levels showed that the frequencies of the propeller noise components did not agree precisely with values computed from given values of the propeller rpm.

This discrepancy is illustrated in Figure 8 which shows the ratio of measured blade passage frequency to nominal blade passage frequency as a function of airplane indicated airspeed. The measured frequency was obtained directly from narrowband spectra, associated with maximum A-weighted sound level (without corrections for Doppler shift); the nominal frequency was determined from the FAA-quoted value for the propeller rpm. Two comments can be made. First, the data show a fairly large range of scatter, due to the inaccuracies inherent in measuring blade passage frequency at a time when the Doppler shift is varying most rapidly. Secondly, in spite of the data scatter, there appears to be an increase in the frequency ratio as airspeed increases.

One proposed explanation for the discrepancy was that the rpm values were in error. This explanation is reasonable in view of the 180 rpm error (6.7% of nominal) discovered by FAA for the Cessna 210. Checks were performed by BBN on results for two aircraft, the Cessna 210 and Piper PA-42. Narrowband spectra were analyzed at the beginning and end of a run, and values were determined for the apparent blade passage frequency. Adjustments were made to take into account the Doppler frequency shift, the two resulting values for the true blade passage frequency were averaged, and the corresponding propeller rpm was calculated. The results are as follows:-

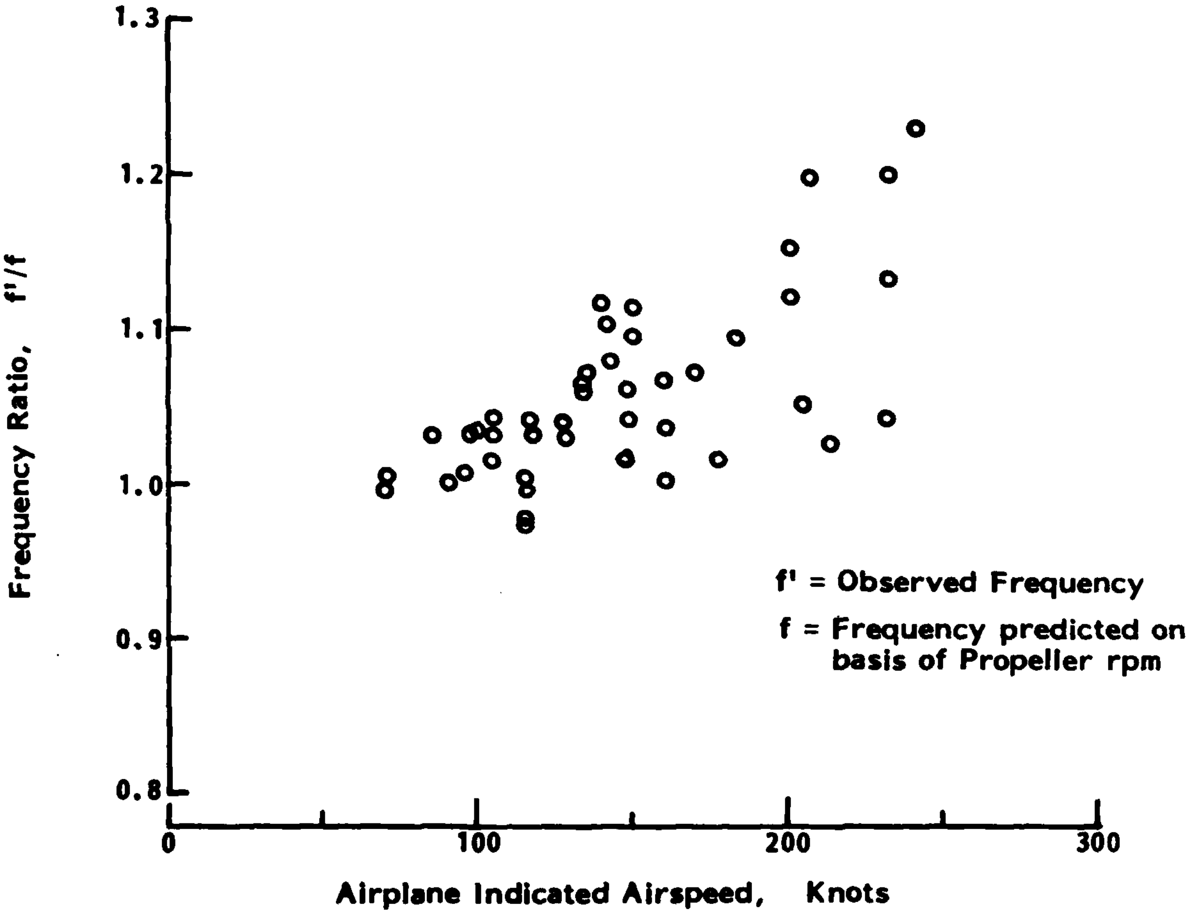


FIGURE 8. APPARENT PROPELLER BLADE PASSAGE FREQUENCY ASSOCIATED WITH MAXIMUM A-WEIGHTED SOUND LEVELS

Airplane	Run	Nominal rpm	Estimated rpm	Discrepancy
Cessna 210	A2	2880	2897	0.6%
Cessna 210	G20	2880	2909	1.0%
PA-42	9	1850	1878	1.5%
PA-42	23	2000	2004	0.2%

It is concluded that, although there are probably some discrepancies between nominal and actual values for the propeller rpm, the differences are not large and do not account for the frequency shifts observed in the data and plotted in Figure 8.

A second explanation is that the directivity characteristics of propeller noise result in the maximum observed A-weighted sound level being generated before the airplane is overhead. The observed value for the blade passage frequency will then be higher than expected because of Doppler shift effects. To explore this possiblity the data in Figure 8 were converted to show the relationship between apparent propagation angle and airplane Mach number, using conventional Doppler frequency shift equations. The results are plotted in Figure 9. The data scatter has increased because of the sensitivity of the analysis to small changes in apparent frequency. However a regression line fitted to the data shows a general trend of decreasing angle (relative to the horizontal) with increasing Mach number. That is, the angle of maximum acoustic radiation moves forward as airplane Mach number increases.

The data are consistent with results obtained by Hanson [1] from his theoretical model. Figure 10, reproduced from Reference 1, shows computed directivity patterns for three harmonics and one airplane Mach number. The patterns are different for thickness and loading noise components but, with one exception, the maximum radiation is forward of the propeller plane of rotation. Angles

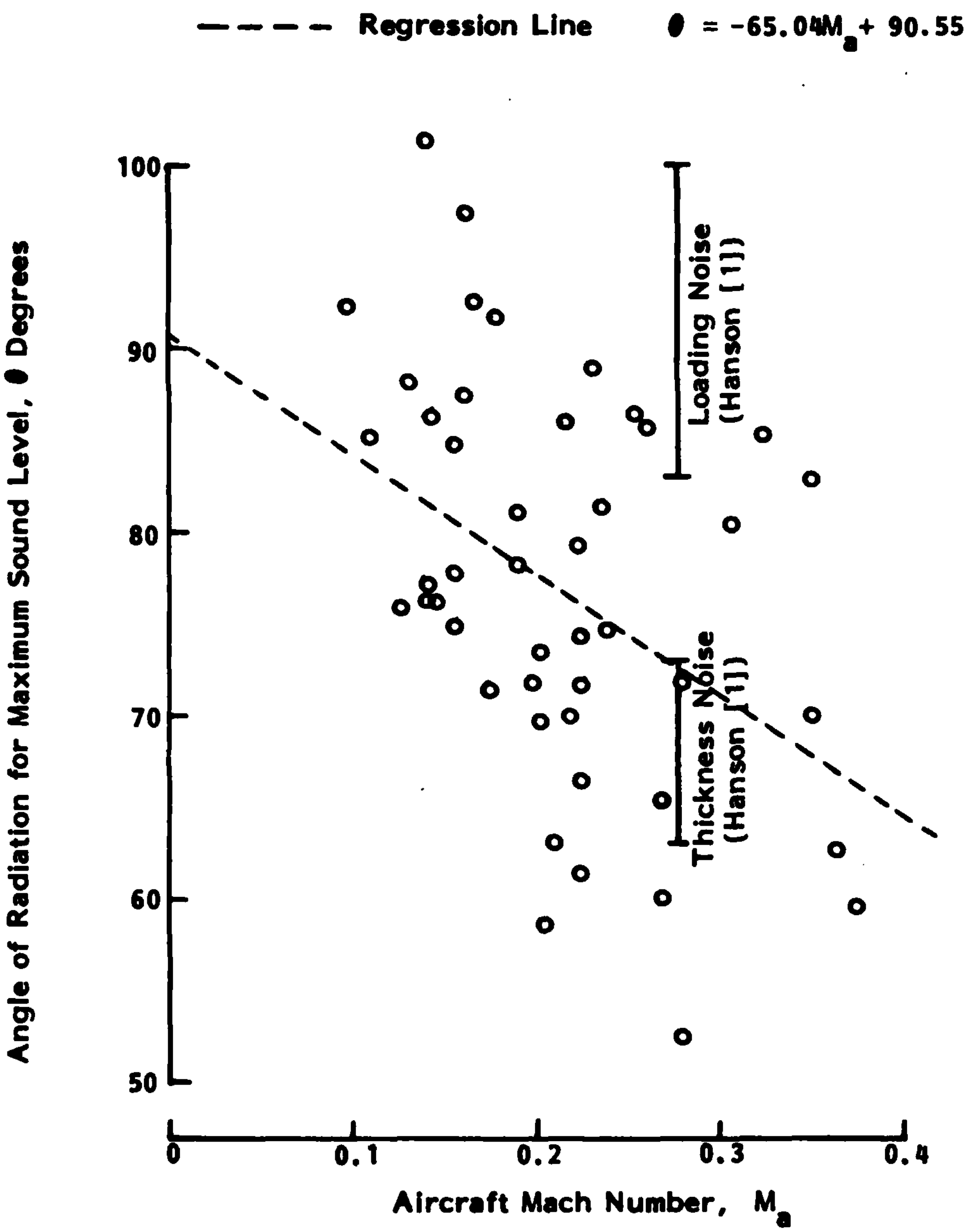


FIGURE 9. ESTIMATED DIRECTIVITY ANGLE ASSOCIATED WITH MAXIMUM A-WEIGHTED SOUND LEVEL AS A FUNCTION OF AIRCRAFT MACH NUMBER

for maximum sound level obtained from Figure 10 are superimposed on the data in Figure 9. It is seen that directivity angles computed for thickness noise lie close to the regression line for the test data, whereas angles associated with loading noise lie at the upper range of the measured data.

It is concluded from this simple analysis that the observed increase in blade passage frequency is associated with propeller noise directivity effects and the influence of Doppler frequency shifts.

One corollary of this conclusion is that, as airplane Mach number increases, the distance between the airplane and observer, at the time of emission of the maximum sound levels, will also increase. However, the increase in attenuation due to the longer propagation path is small. For example, if it is assumed that the airplane Mach number increases from 0.1 to 0.3, the increase in attenuation of the peak sound levels due to spherical spreading during propagation from source to receiver is about 0.4 dB.

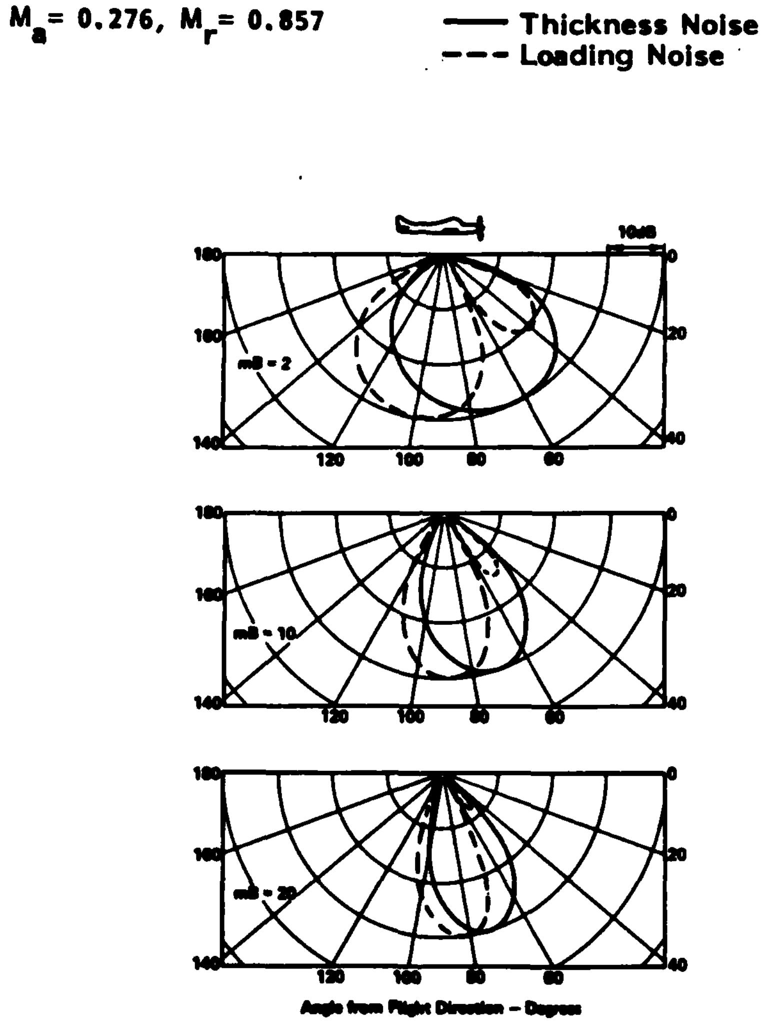


FIGURE 10. CALCULATED DIRECTIVITY PATTERNS FOR THICKNESS AND LOADING NOISE FOR A BLADE ELEMENT AT 80% RADIUS; TYPICAL MACH NUMBERS FOR GENERAL AVIATION PROPELLER FLYOVER [1]

6.0 PROPELLER TIP MACH NUMBER

Propeller tip Mach number is of particular interest because of the strong effect on propeller noise generation. Propeller noise prediction procedures utilize either tip rotational or helical Mach numbers as important parameters. Reviews of some of these methods are contained in References 2 and 3. The empirical relationships include tip Mach number terms ranging from the 6th power of Mach number to the 24th power.

In most of the empirical prediction procedures tip helical Mach number is used rather than tip rotational Mach number. Consequently, in the present investigation of the measured take-off and flyover sound levels, the initial selection of flyover test conditions was based on the choice of tip helical Mach numbers which correspond most closely to those for take-off. Since the aircraft speeds in the flyover test were higher than those for take-off tests, the criterion of similar helical Mach numbers resulted in the selection of lower engine speeds for flyover than for take-off. As the analysis progressed it became apparent that, for similar values of helical Mach number, the sound levels at harmonics of the blade passage frequency tended to be higher at take-off than for flyover. Consequently, the analysis was expanded to include flyover runs at the same tip rotational Mach number (or same propeller rpm) as for take-off.

Data for the Beech B58 airplane provide a good illustration of this phenomenon. Representative narrowband spectra from Appendix B are reproduced in Figure 11. The spectrum in Figure 11(a) is associated with take-off conditions with a propeller tip helical Mach number of 0.840 and a rotational Mach number of 0.821. Figure 11(b) presents flyover noise data for conditions with a tip helical Mach number of 0.846 (close to take-off conditions) and a rotation Mach number of 0.790. Finally, Figure 11(c) contains flyover noise data for a helical Mach number of 0.858

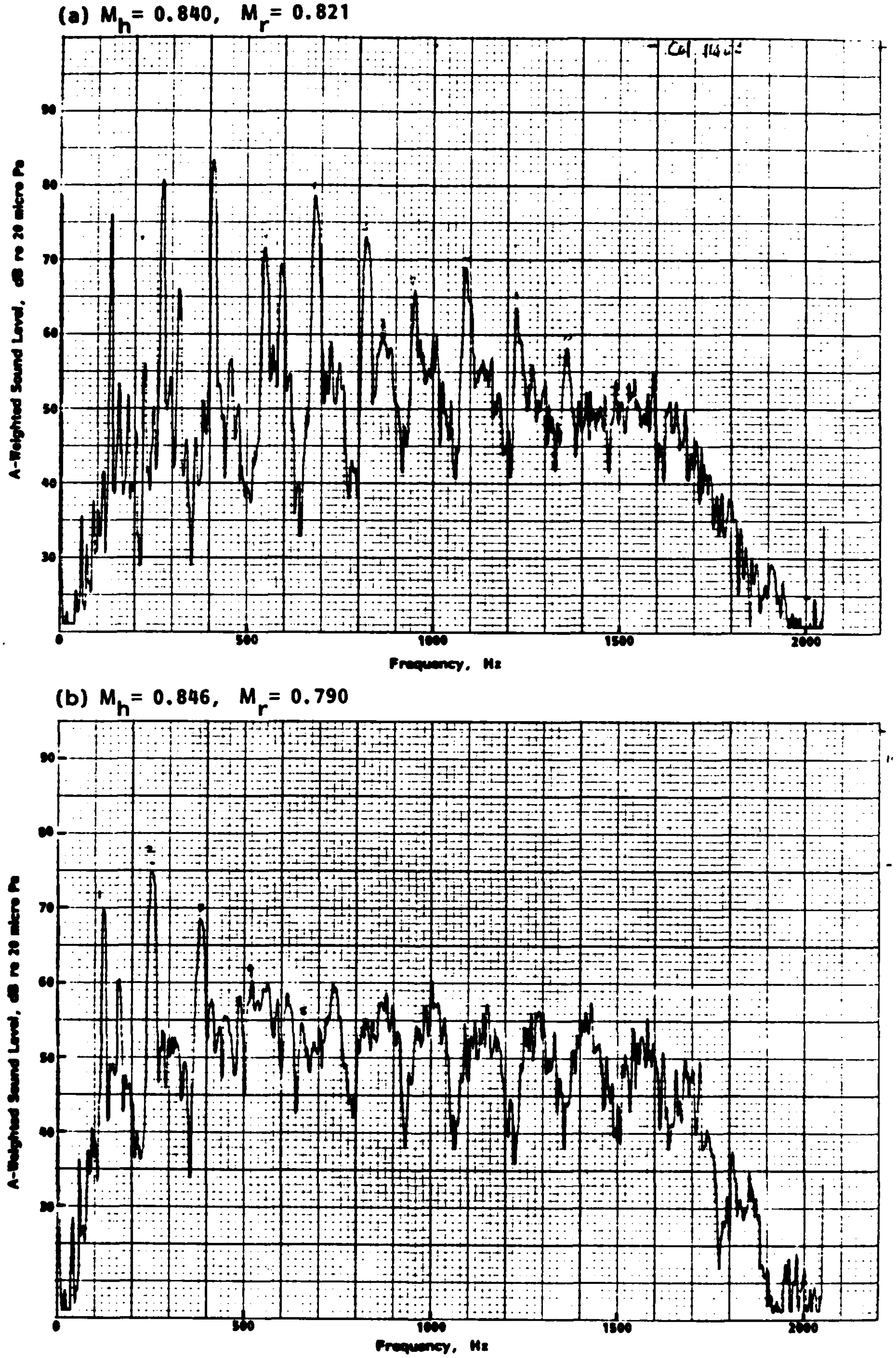


FIGURE 11. COMPARISON OF NARROWBAND SOUND LEVEL SPECTRA FOR BEECH B58 OPERATING AT DIFFERENT PROPELLER TIP MACH NUMBERS

(c) $M_h = 0.858$, $M_r = 0.821$

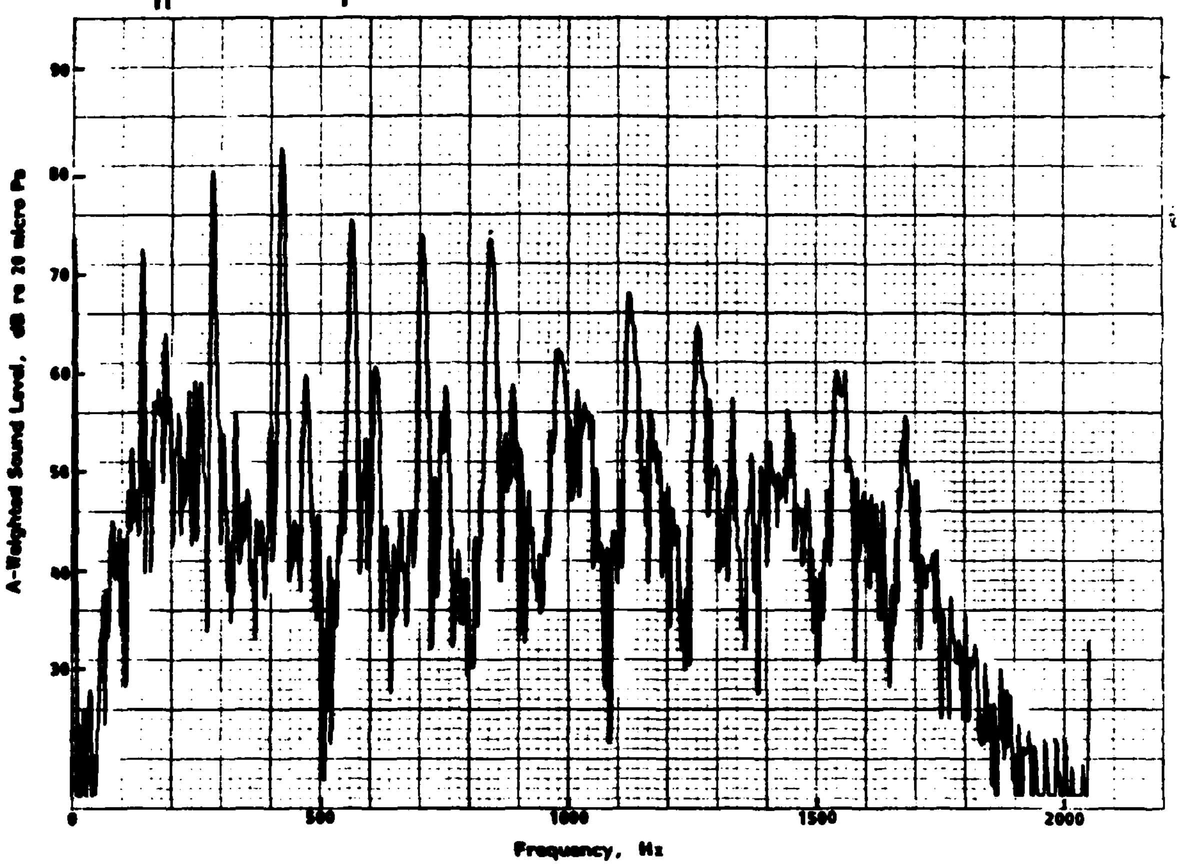


FIGURE 11. CONTINUED

(higher than take-off) and a rotational Mach number of 0.821 (equal to the take-off value). The sound levels have not been normalized with respect to aircraft altitude but the actual range of altitudes is small so that the relative adjustments would be no more than 1.1 dB.

It is immediately evident that the harmonic content in the spectrum of Figure 11(a) is much greater than that in Figure 11(b), whereas Figures 11(a) and 11(c) have similar harmonic content. Consequently, it appears that tip rotational Mach number should be the critical parameter rather than helical Mach number.

The analysis can be taken one step further by means of the harmonic levels contained in the figures of Appendix D. In these figures flyover data associated with propeller rpm values which are the same as take-off values are distinguished from other flyover sound levels. The results at certain harmonics are confused somewhat due to destructive interference effects associated with reflections from the ground surface, but there is a general trend that harmonic levels for flyover conditions are in closer agreement with take-off values when tip rotational Mach number is used as the criterion than when helical Mach number is used. The effect is particularly marked for the Beech B58, Cessna 414, Piper PA-28 and Piper PA-42. These aircraft have propellers with relatively high tip Mach numbers (as shown in Figure 2).

In the case of the Cessna 210, which has a significantly higher tip Mach number than any of the other seven test aircraft, all data analyzed refer essentially to the same propeller rpm. Thus the results in Figures D.3 and D.4 show mainly the extent of the data scatter rather than a comparison of rotational and helical Mach number effects. Measurements were made by FAA over a range of engine rpm and analysis of these additional data may be worthwhile at some future date.

The use of rotational Mach number rather than helical Mach number as the critical parameter in determining propeller noise levels is not without precedent. The SAE prediction procedure for far-field propeller airplane noise [4] utilizes rotational Mach number to predict the overall sound pressure level, although helical Mach number is introduced when converting from sound pressure level to perceived noise level or A-weighted sound level. Furthermore Hanson [1] derives analytical expressions for thickness and loading (dipole drag and lift) noise which contain rotational tip Mach number as a parameter. His relationships show thickness noise to be strongly dependent on rotational Mach number whereas lift noise is dependent more on helical Mach number. A brief discussion of Hanson's equations was presented in Reference 2.

7.0 DISCUSSION

There are several questions regarding a change from flyover to take-off tests as a means of noise certification for small propeller-driven aircraft. However, it is not realistic to expect that the present, preliminary, study can answer them all. Furthermore, there is an inherent danger that a brief study of this type might draw too many conclusions which are speculative in nature. Consequently, this discussion should be viewed as only one step in advancing the understanding of take-off and flyover sound levels generated by small propeller-driven aircraft.

The results can be looked at from two points of view. First, the results provide information which can be used to improve current prediction methods. Secondly, the results can be considered relative to the drawing up of noise certification levels for use with take-off rather than flyover test procedures.

Consider first the understanding of the physical phenomena involved in propeller noise generation and propagation. Several parameters are involved, including propeller tip Mach number, propeller noise directivity, sound reflection from the ground, engine exhaust noise and aircraft angle of attack. Some of these parameters have been discussed in preceding sections with respect to their influences on the comparison between flyover and take-off sound levels. On the basis of the test data, the influences of directivity and reflections from the ground surface seem to be relatively small. That is not to say that reflections from the ground and microphone height do not have significant effects on the actual values of the measured sound levels. It is simply that the effects are probably similar for take-off and flyover measurements.

Propeller tip Mach number and exhaust noise do play an important role in noise prediction procedures and measured sound levels under different conditions. The prediction procedures are essential to the extrapolation of measured sound levels of existing airplanes to different flight conditions, and in the estimation of sound levels for new aircraft. Galloway, in his review of empirical procedures for the prediction of sound levels produced by small propeller-driven airplanes in flight [3], comments that there is no agreement amongst investigators regarding the dependence of sound level on tip Mach number, or even on whether rotational or helical Mach number is to be used. However, the preponderance of the reported work uses helical Mach number. Results of the present study suggest that rotational rather than helical Mach number is the more appropriate parameter.

If sound levels for take-off and flyover conditions are compared on the basis of equal rotational Mach number the agreement should be better than if helical Mach number is used as the criterion. However, there still appears to be a general trend that the sound levels are higher for take-off than for flyover. One additional parameter which has not been explored in this study is that of airplane angle of attack. There is some indication [5] that angle of attack increases discrete frequency propeller noise. Measurements were made by FAA on a Cessna 210 at different take-off airspeeds in order to investigate the effect of angle of attack. Detailed analysis of the data was outside the scope of the present study, although data for three of the airspeeds are presented in this report. One problem in performing such an analysis is the determination of the airplane angle of attack. Simple analysis on the basis of airspeed indicates that at most harmonics the sound level decreases as airspeed increases. An exception appears at the fundamental of the blade passage frequency where the sound level increases with airspeed. Further analysis of the data would, however, appear to be justified.

The applications of this analysis with respect to noise certification are more nebulous. First, the integration time used in the measurement of the A-weighted sound levels may cause an underestimate of the levels for flyover conditions where the sound levels change very rapidly with time in the neighborhood of the peak level. Part of this effect results from the low altitude used in the flyover tests; the effect would be less if an airplane altitude of 1000 ft were used for the measurements. (The mean altitude for the flyover tests analyzed in this report was 548 ft, with a standard deviation of 63 ft, whereas the mean and standard deviation for take-off were 820 ft and 309 ft, respectively).

Secondly, in extrapolating noise certification sound levels from flyover to take-off conditions, the propeller type rotational Mach number should be used instead of helical Mach number as the controlling parameter. However, there is the added complication in that the precise manner in which angle of attack is taken into account is still unspecified.

Finally, the question raised by Galloway [3] regarding differences between single-engined and twin-engined airplanes is unresolved. By chance, most of the aircraft analyzed in this study were twin-engined. Within this category it was observed that under high-speed flyover conditions, discrete frequency propeller noise constituted a smaller fraction of the overall sound pressure than for lower speed flight at the same propeller helical Mach number. It has not yet been determined whether the broadband noise emanates from the engine exhaust or is associated with aerodynamic noise of the airplane itself.

8.0 CONCLUSIONS

An analysis by FAA of take-off and flyover sound levels measured for several general aviation propeller-driven aircraft indicated that the take-off sound levels were higher than anticipated on the basis of previous flyover test data. The preliminary spectral analysis discussed in this report indicates that the higher take-off sound levels are associated with greater contributions from the harmonics of the propeller blade passage frequency. Existing empirical prediction procedures are based on propeller tip helical Mach number as the critical parameter, whereas the present study indicates that tip rotational Mach number is more appropriate.

The complexities of interference phenomena covered by measurements from a 4-foot-high microphone, the effects of Doppler shifts, and the inherent inaccuracies associated with narrowband frequency analyses of a time-varying signal make accurate quantitative comparisons difficult. Nevertheless, the sound pressure levels of particularly the first few propeller harmonics are up to 10 decibels greater during take-offs than during flyovers. These differences result in maximum A-weighted sound levels for take-offs that are of the order of 3 decibels greater than for flyovers at comparable helical or rotational Mach numbers. One possible explanation (not investigated in detail in this study) is that propeller noise generation may vary with airplane angle of attack. In addition, the integration time used in data acquisition may be significant, particularly for high-speed, low-level flyovers where the sound levels change very rapidly at the observer location during the integration period.

Propeller noise directivity and reflected sound from the ground surface also influence the measured sound levels produced by an airplane in flight. Although these effects may be significant in determining the actual sound levels measured by a microphone at a given location, the relative effects between flyover and take-off conditions appear to be small.

REFERENCES

1. D.B. Hanson, "Influence of Propeller Design Parameters on Far-Field Harmonic Noise in Forward Flight", AIAA Journal, **18**, 11, 1313-1319 (1980).

2. W.J. Galloway, J.F. Wilby, "Noise Abatement Technology Options for Conventional Turboprop Airplanes", FAA-EE-80-19 (1980).

3. W. J. Galloway, "A Review of Empirical Procedures for Predicting Sound Levels Produced on the Ground by Propeller-Driven Small Airplanes in Flight", BBN Report 5055 (1982).

4. Anon, "Prediction Procedure for Near-Field and Far-Field Propeller Noise", SAE Air 1407 (1977). (In process of being revised).

5. H.K. Tanna, R.H. Burrin, H.E. Plumblee Jr., "Installation Effects on Propeller Noise", J. Aircraft, **18**, 4, 303-309, (1981).

APPENDIX A
SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA

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SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA

Sequential A-weighted sound level spectra were computed for selected take-off and flyover runs in order to obtain a qualitative presentation of the time histories for the harmonic components. The sequential spectra are contained in this appendix.

The data reduction was performed on an Apple III personal computer using IQS Series 401 FFT Spectrum Analyzer software. The main interest of the analysis was concerned with A-weighted sound levels in the neighborhood of the maximum value. Consequently, the recorded signals were replayed through an A-weighting network (unless the recorded signal was already A-weighted) and reduced for a time sample of about 6 seconds centered approximately on the time of maximum A-weighted level. Because of storage limitations, the total signal could not be stored at a given time. Instead, the data were processed in sample lengths of 1.5 seconds, with each sample length containing 30 spectra at 0.05-second intervals. The 1.5-second data samples were then grouped together to provide a continuous display of sequential spectra.

The 19 figures in this appendix present sequential spectra for one take-off and one flyover for each of the eight aircraft studies. The microphone height was 1.2 m (4 feet) in each case. In some cases spectra were presented for an additional flyover run. The spectra in Figures A.1 through A.19 are arranged such that time increases toward the bottom of the page and the time of maximum A-weighted sound level corresponds, approximately, to the start of the third set of spectra (or end of the second set).

The ordinate scale for the spectra shown in Figures A.1 through A.19 is the A-weighted sound pressure level for an effective bandwidth of 4.6 Hz. However, the value of the spectral level has not been calibrated since the spectra are being used only for a qualitative presentation of the harmonic content.

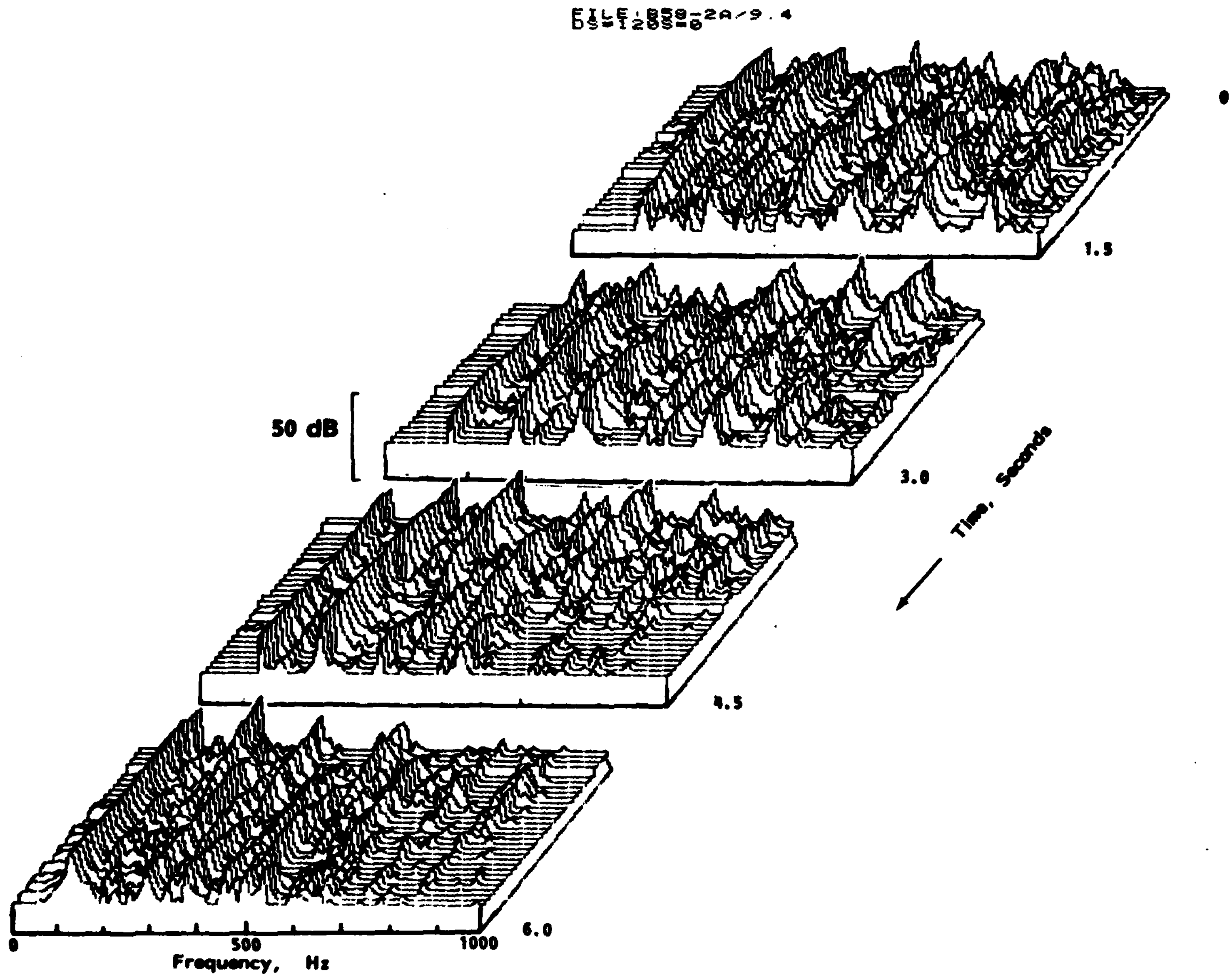


FIGURE A.1 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF BEECH B58P BARON (RUN 2)

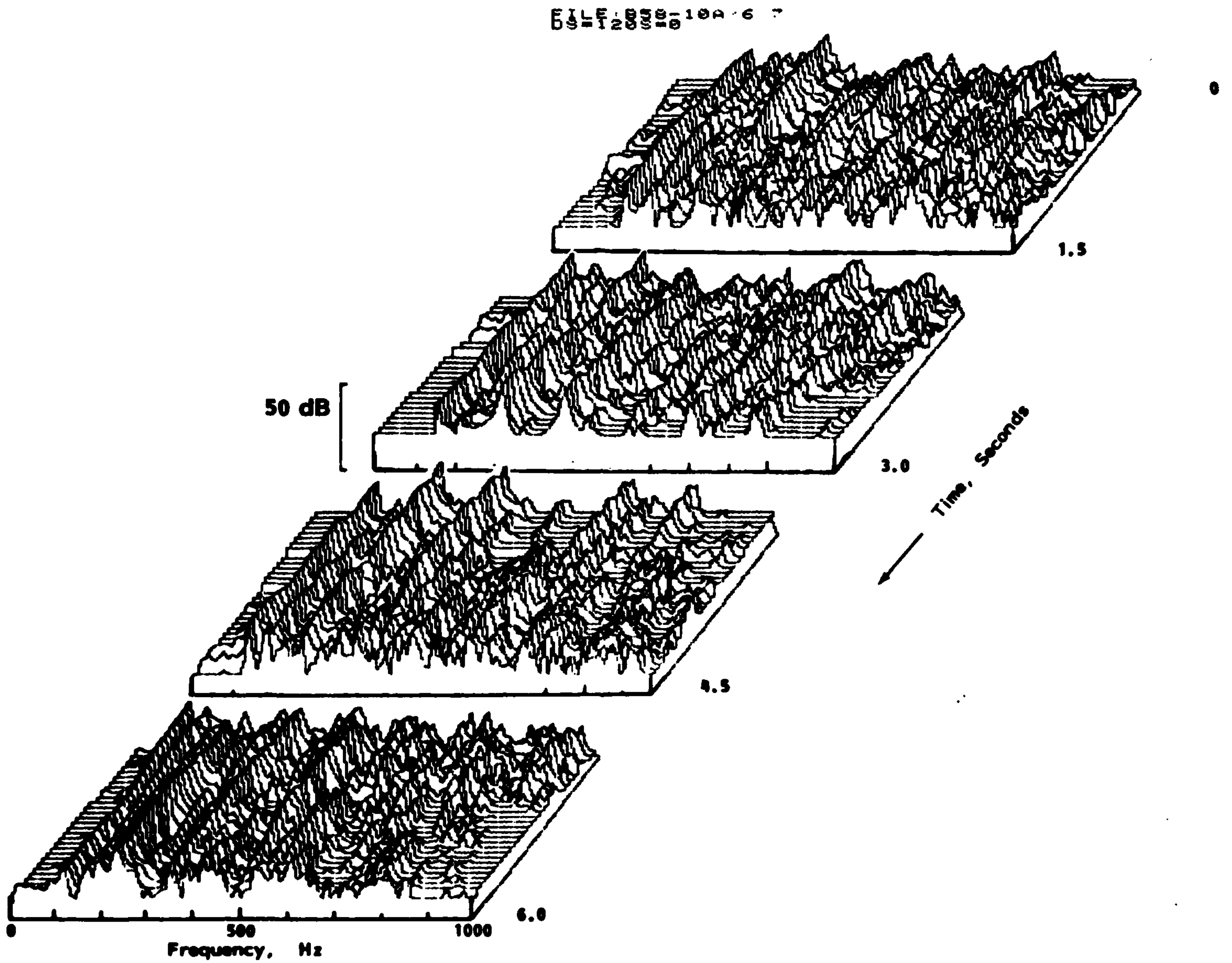


FIGURE A.2 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF BEECH B58P BARON (RUN 10)

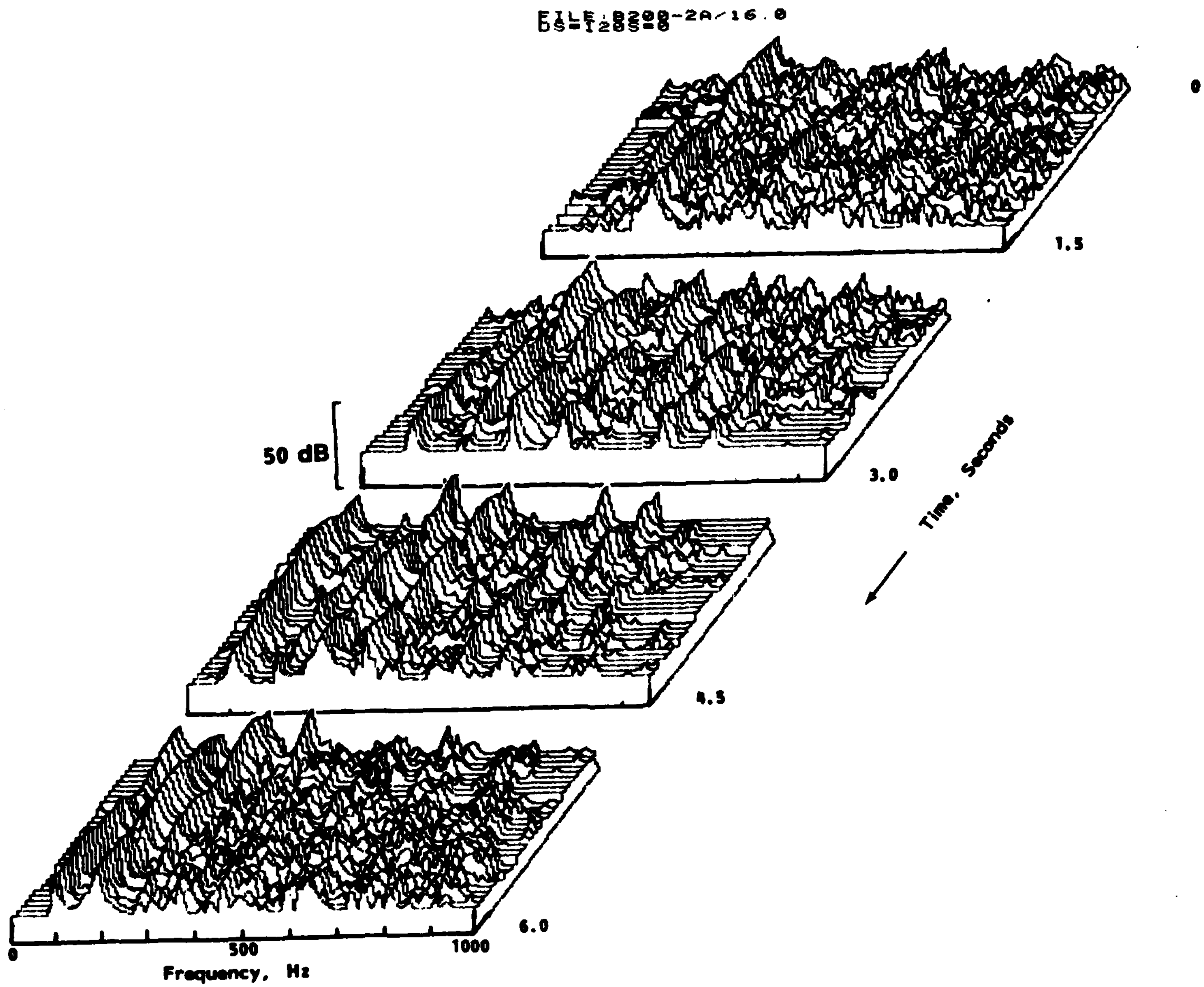


FIGURE A.3 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF BEECH B200 SUPER KING AIR (RUN 2)

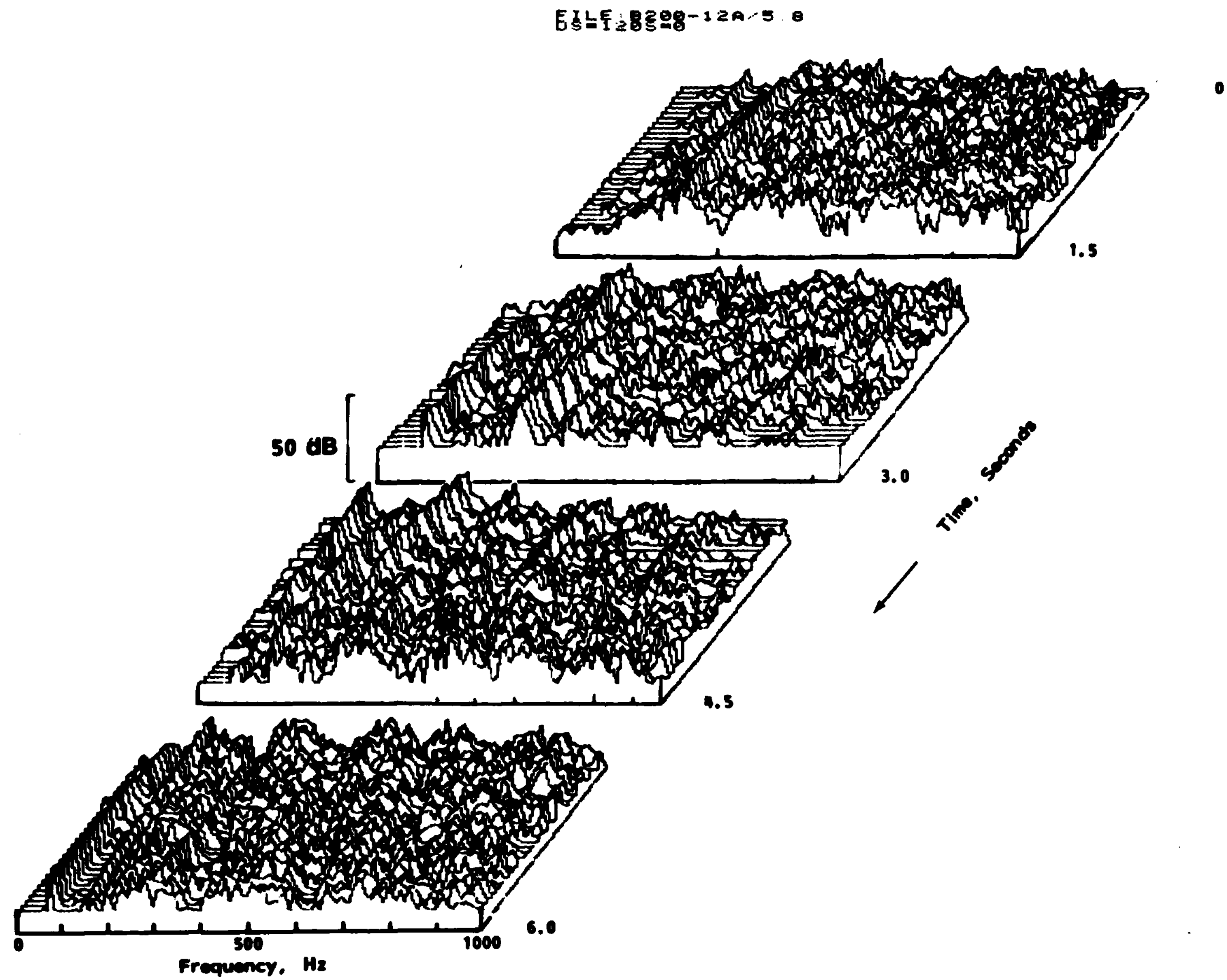


FIGURE A.4 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF BEECH B200 SUPER KING AIR (RUN 12)

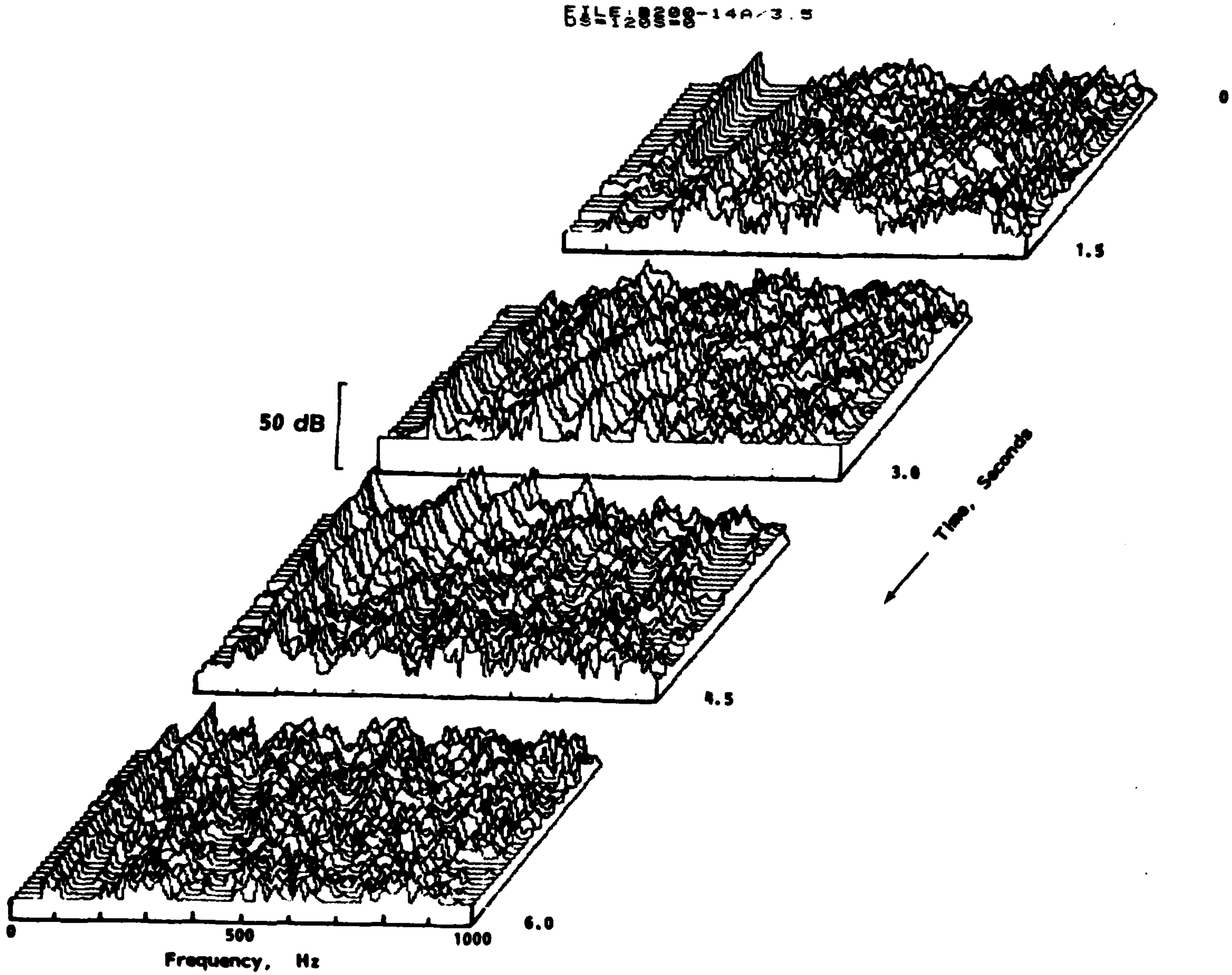


FIGURE A.5 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF BEECH B200 SUPER KING AIR (RUN 14)

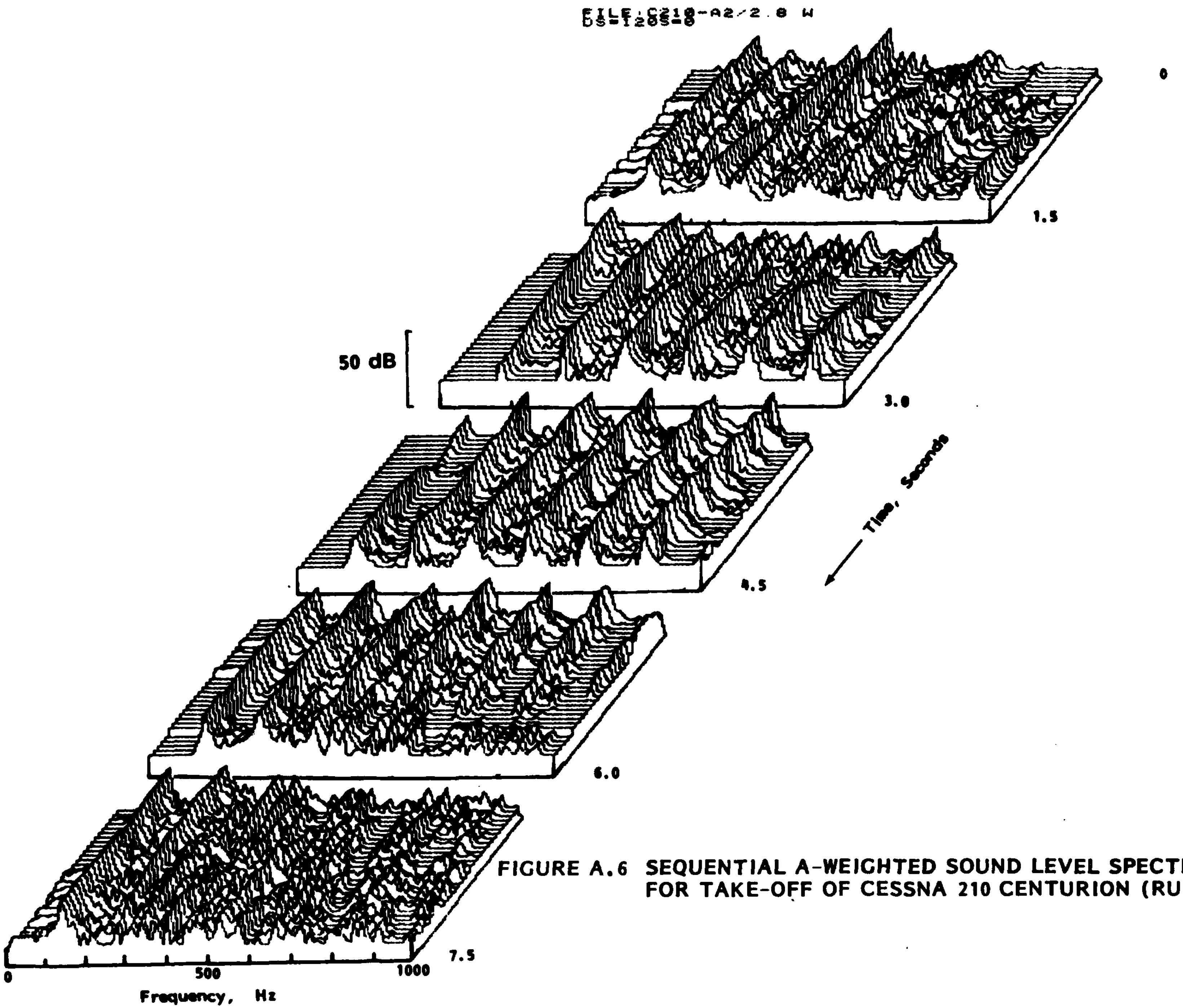


FIGURE A.6 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF CESSNA 210 CENTURION (RUN A2)

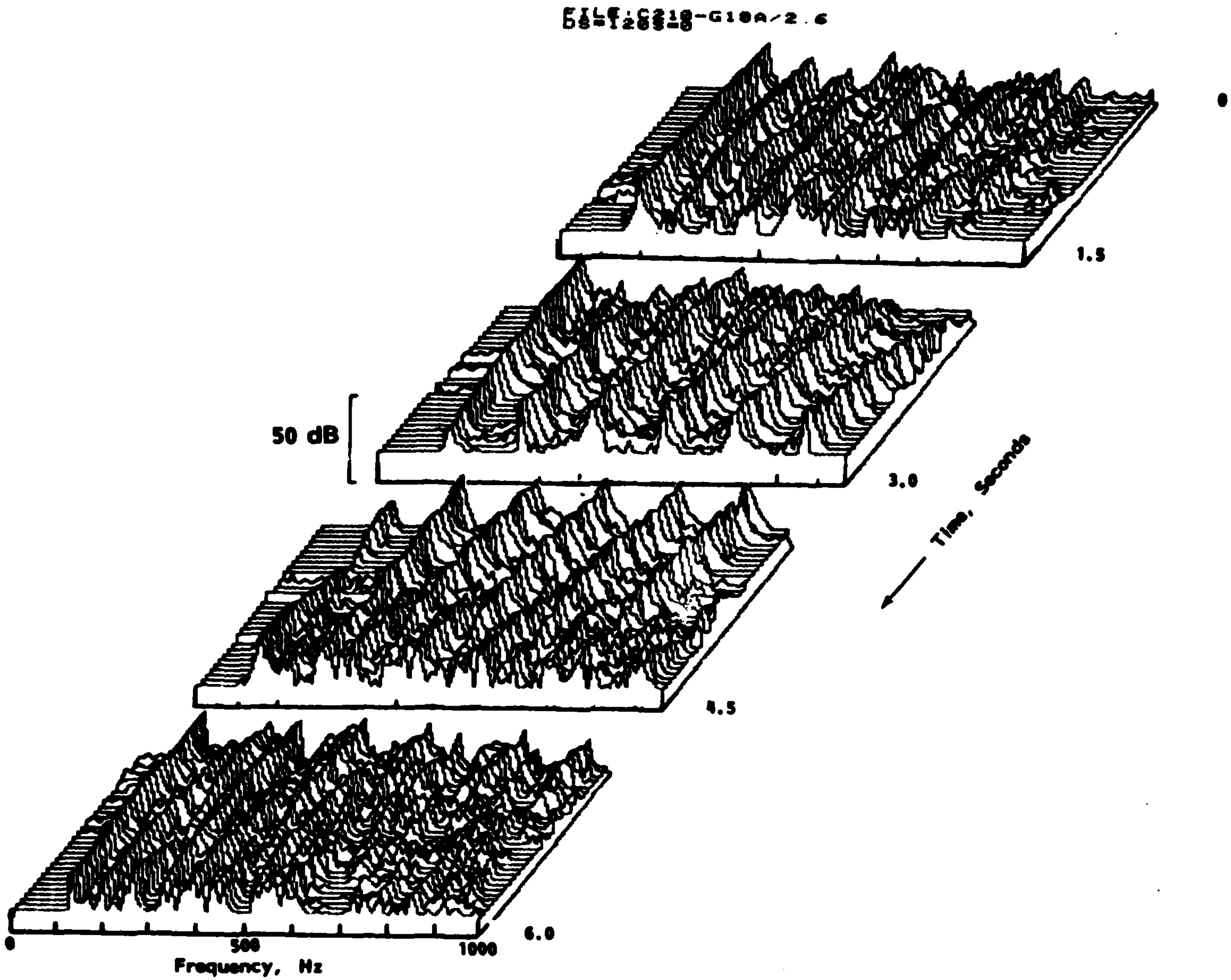


FIGURE A.7 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF CESSNA 210 CENTURION (RUN G18)

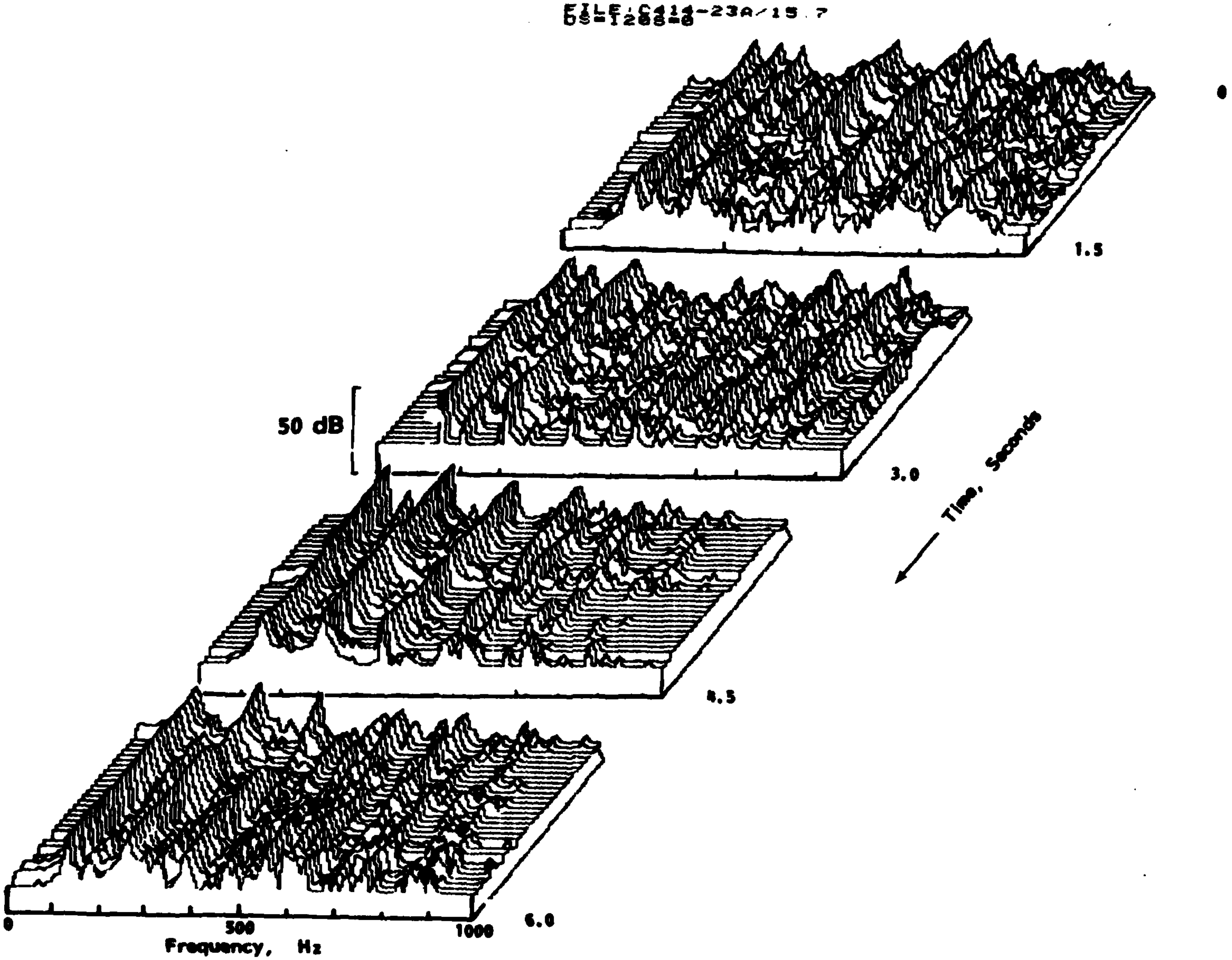


FIGURE A.8 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF CESSNA 414 CHANCELLOR (RUN 23)

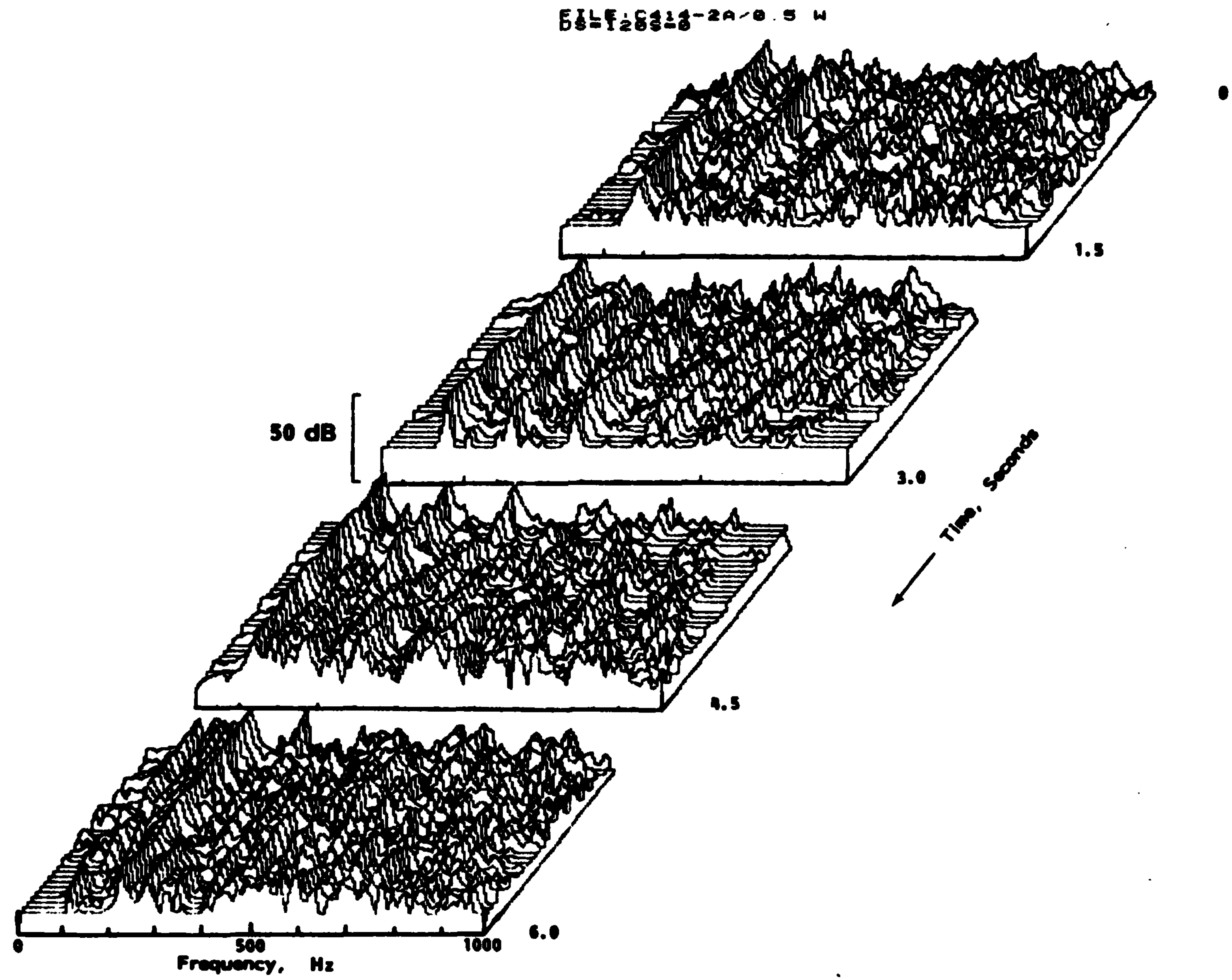


FIGURE A.9 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF CESSNA 414 CHANCELLOR (RUN 2)

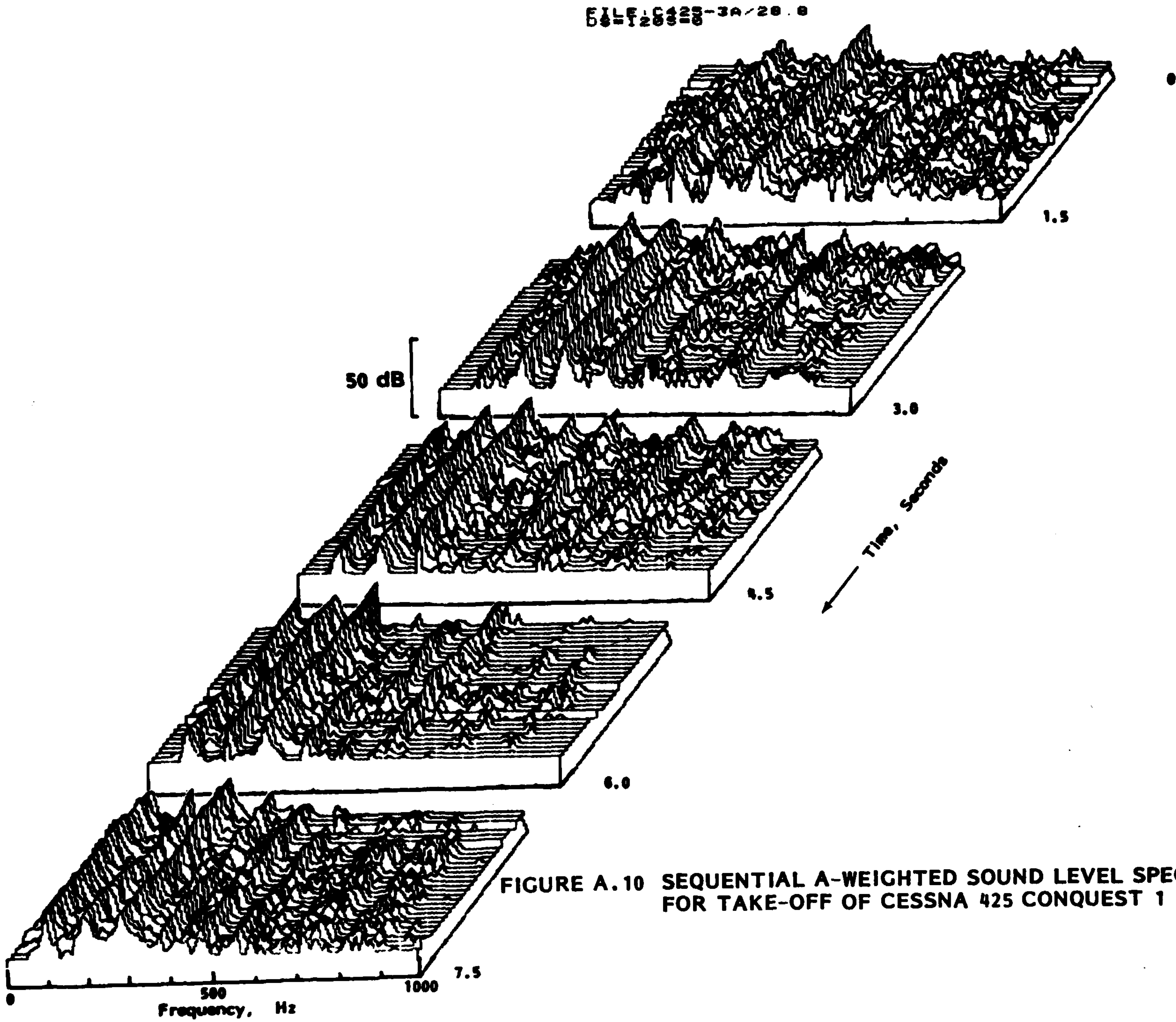


FIGURE A.10 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF CESSNA 425 CONQUEST 1 (RUN 3)

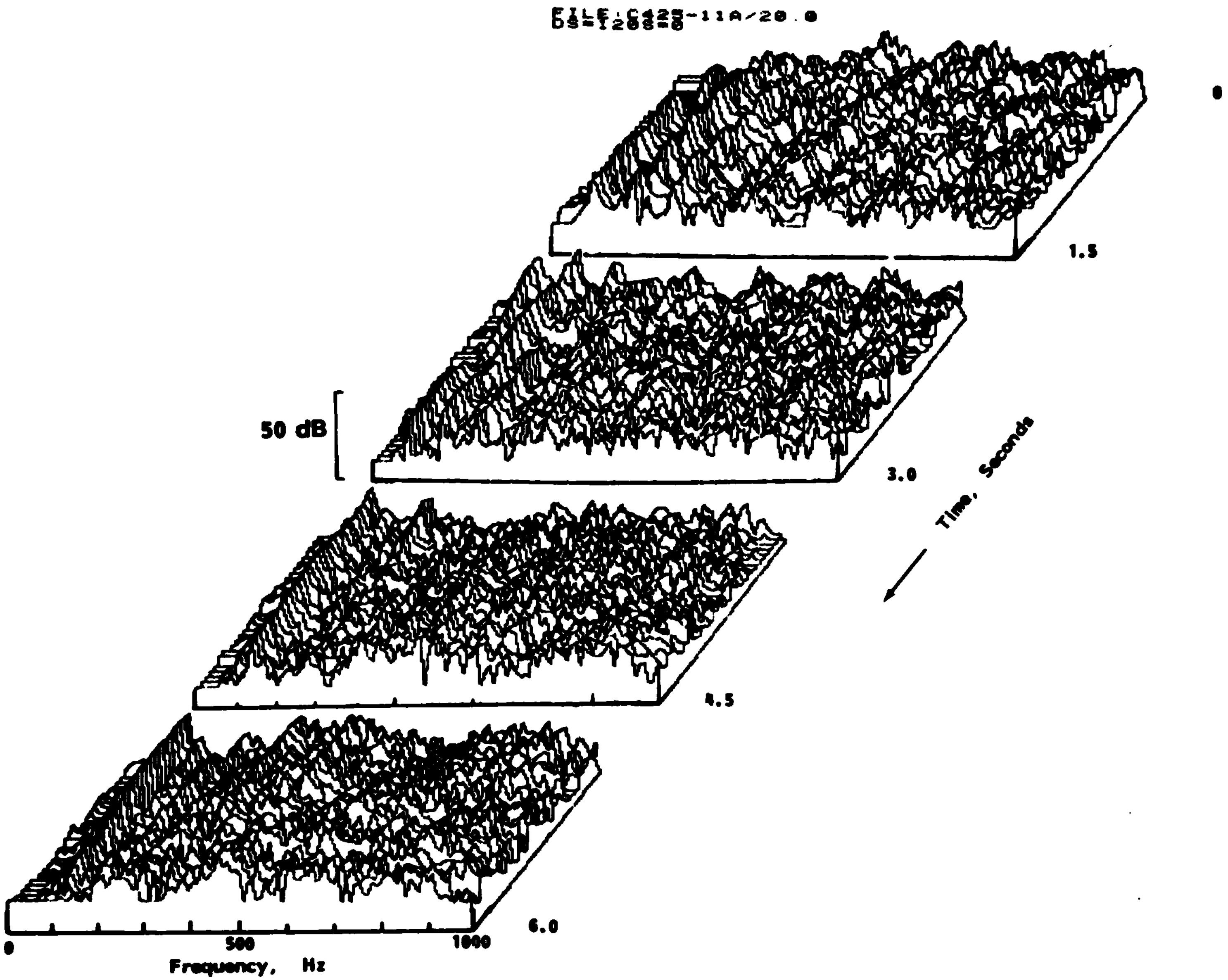


FIGURE A.11 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF CESSNA 425 CONQUEST 1 (RUN 11)

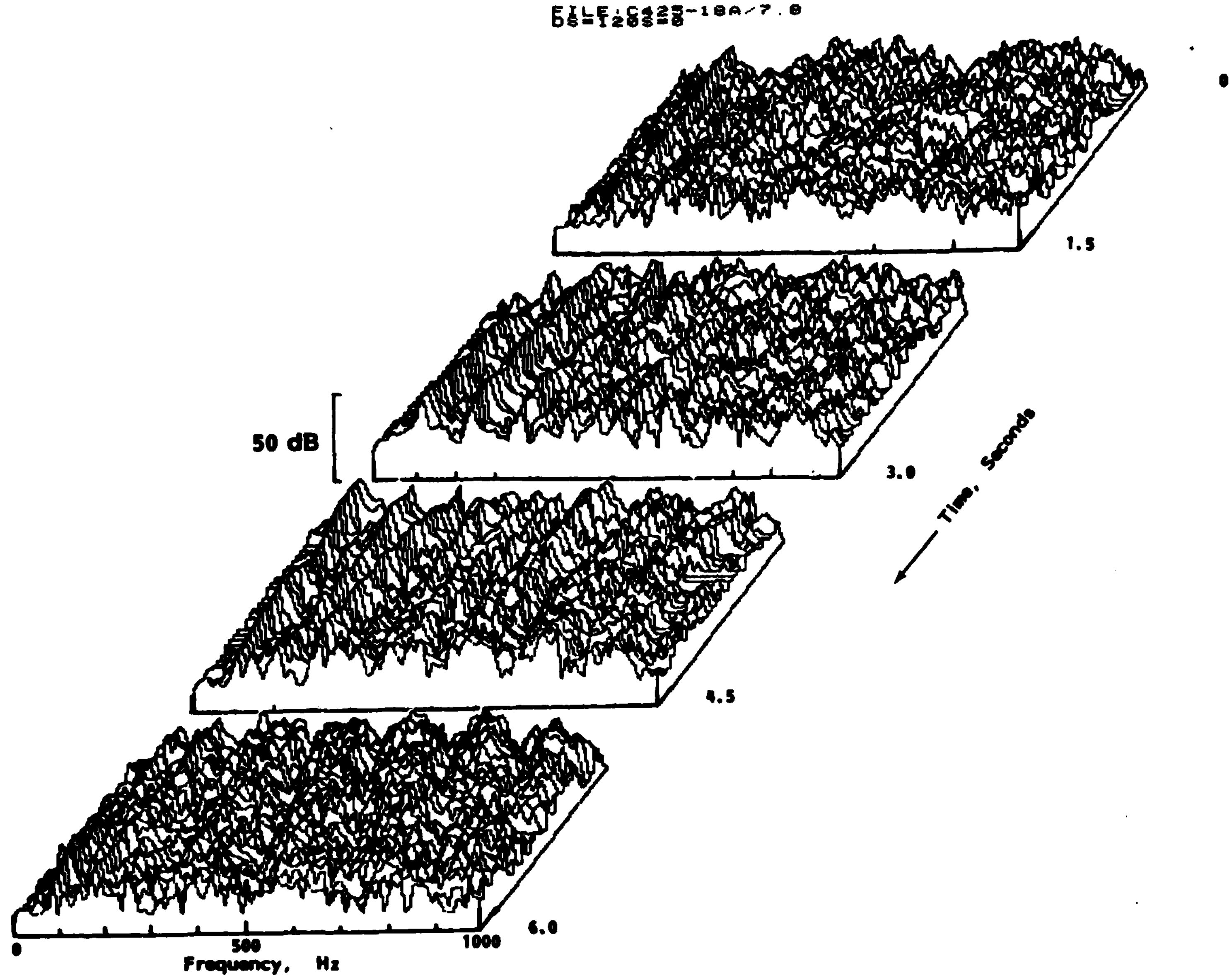


FIGURE A.12 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF CESSNA 425 CONQUEST 1 (RUN 18)

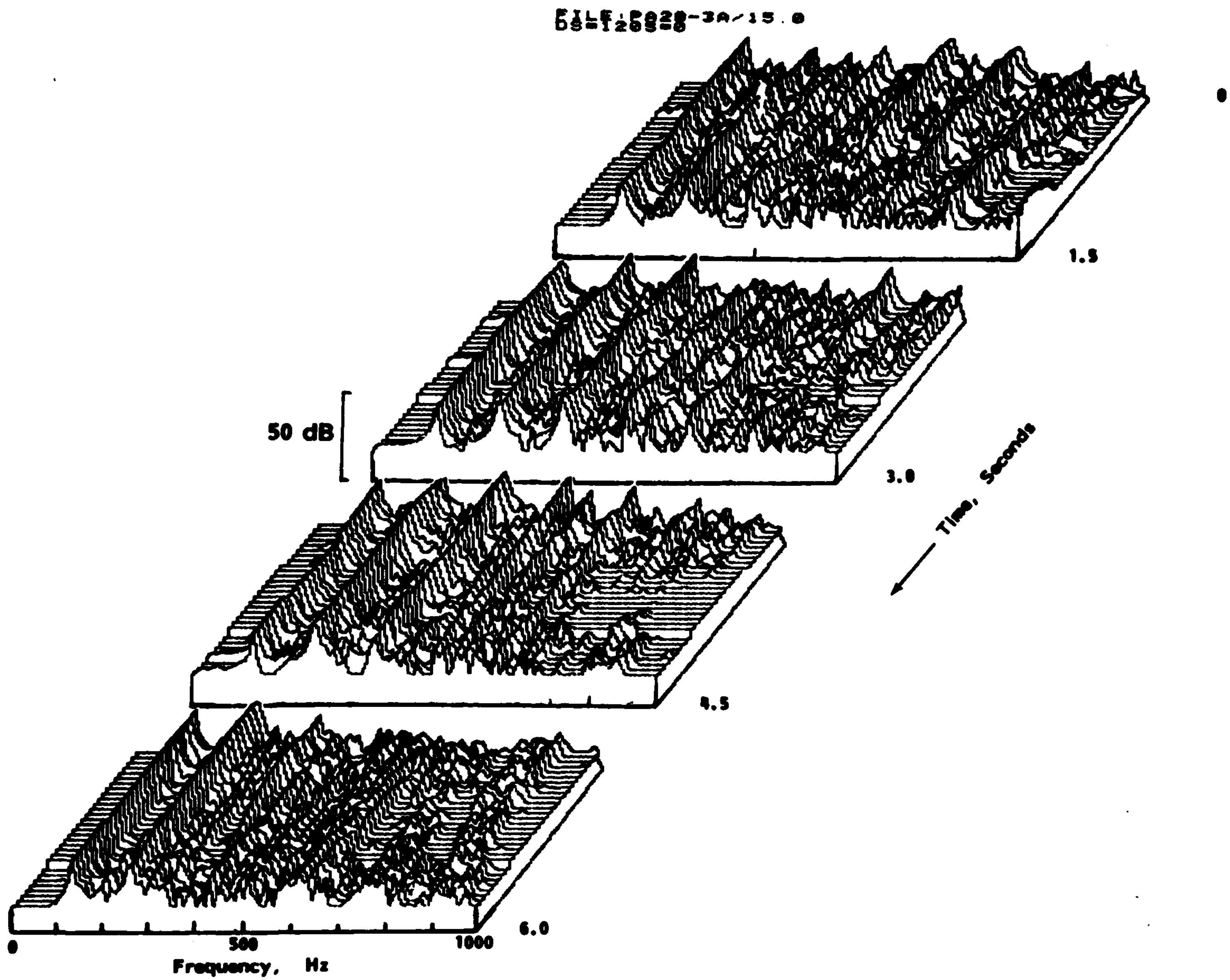


FIGURE A.13 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF PIPER PA-28RT-201T TURBO ARROW IV (RUN 3)

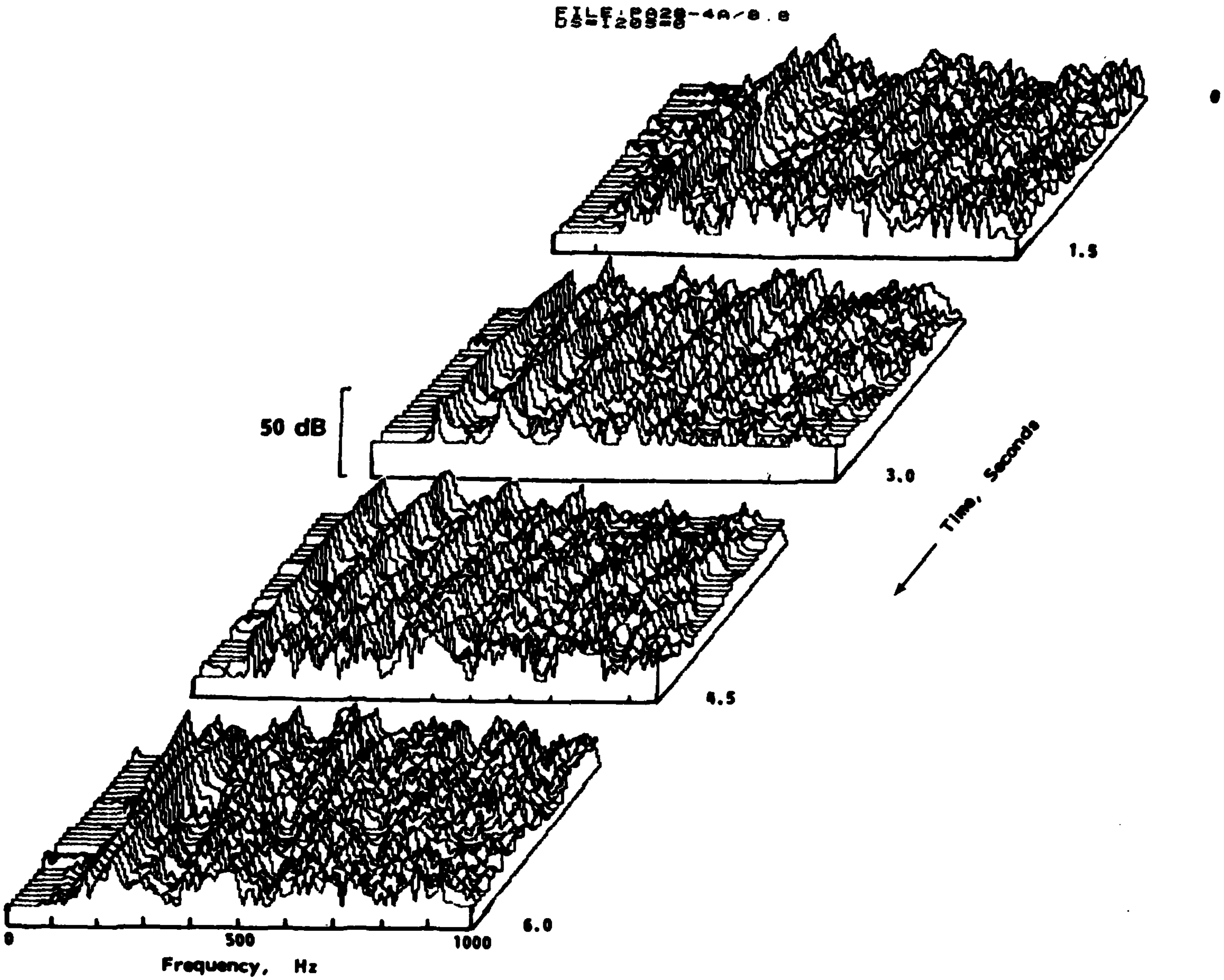


FIGURE A.14 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF PIPER PA-28RT-201T TURBO ARROW IV (RUN 4)

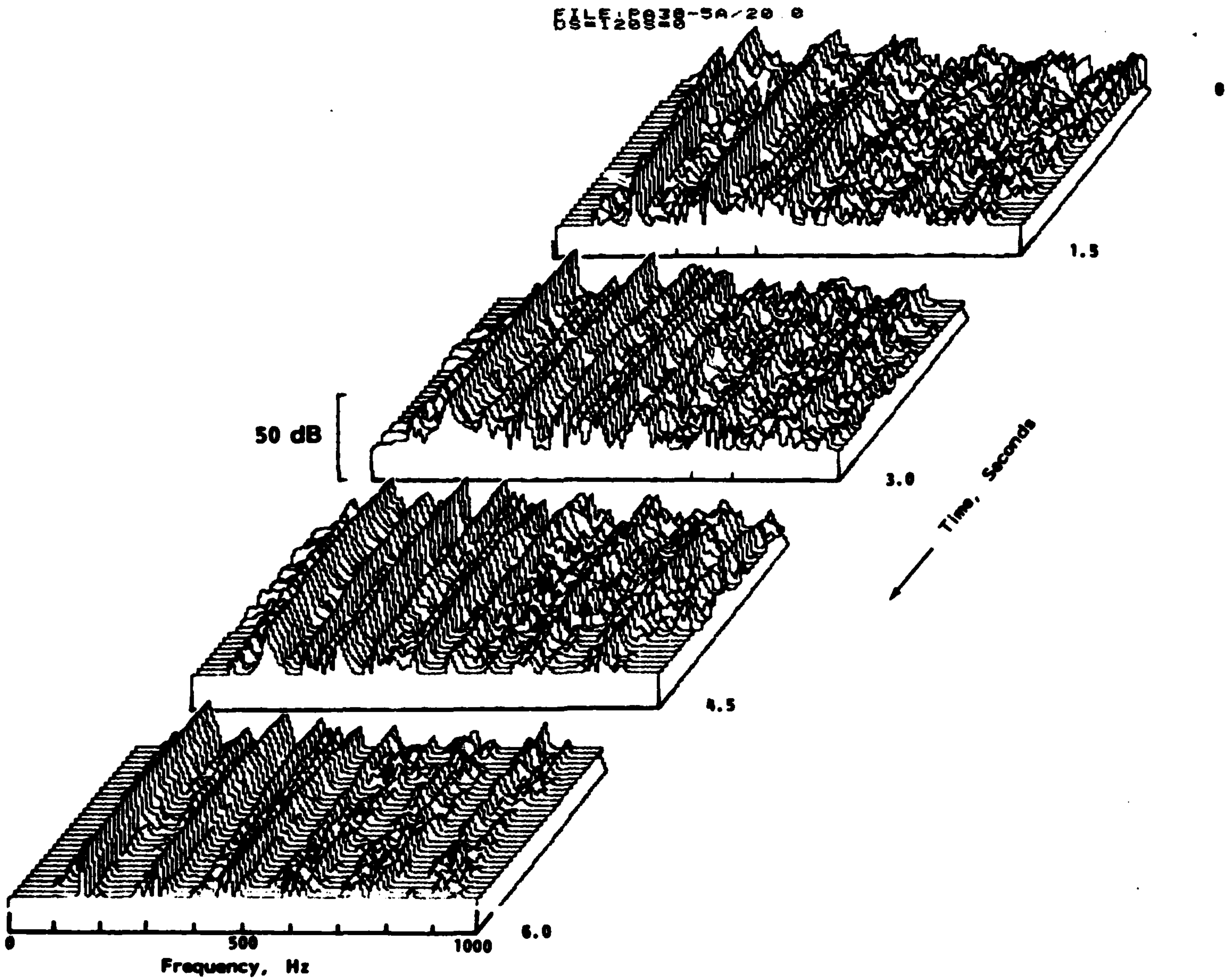


FIGURE A.15 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF PIPER PA-38-112 TOMAHAWK (RUN 5)

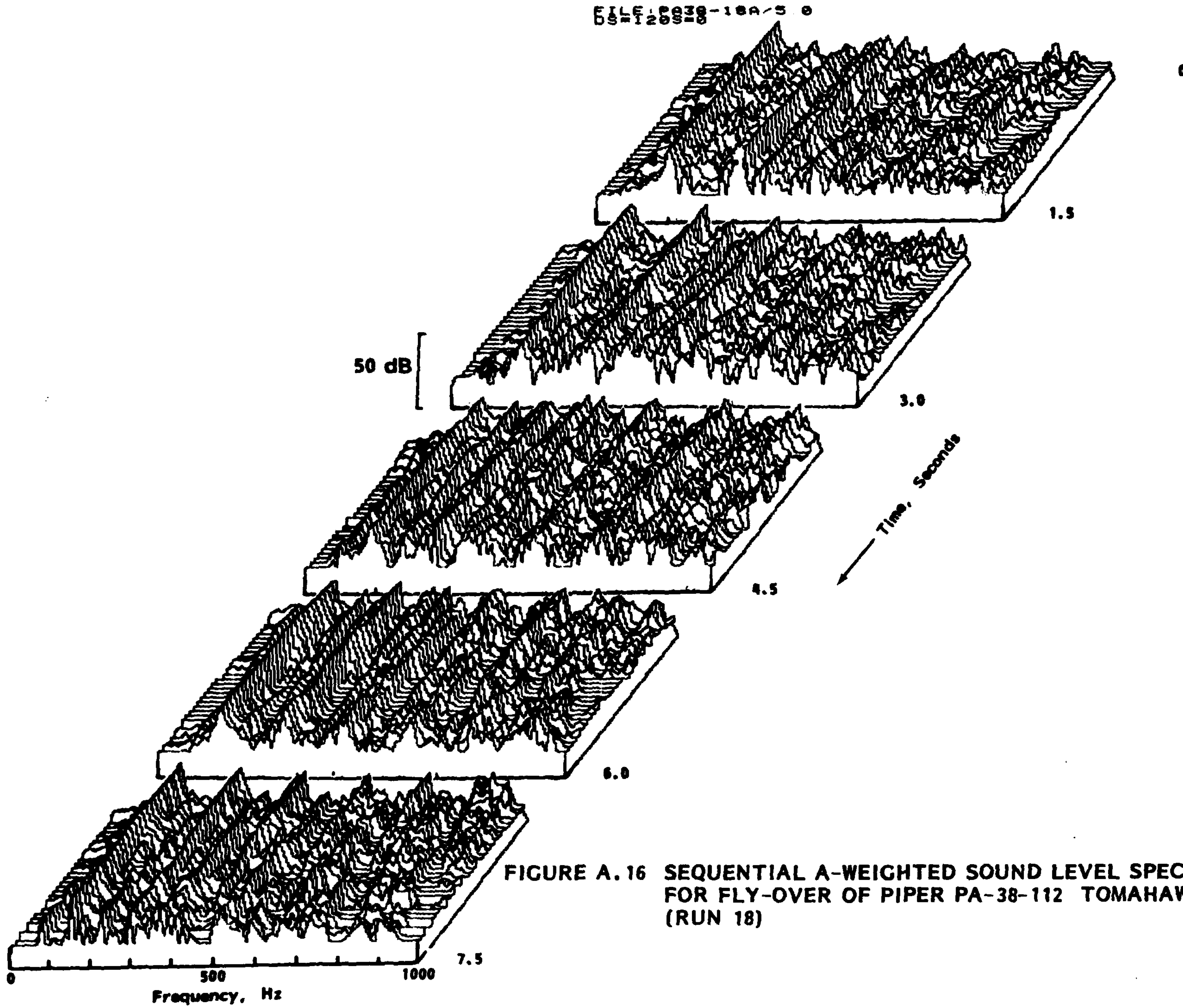


FIGURE A.16 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF PIPER PA-38-112 TOMAHAWK (RUN 18)

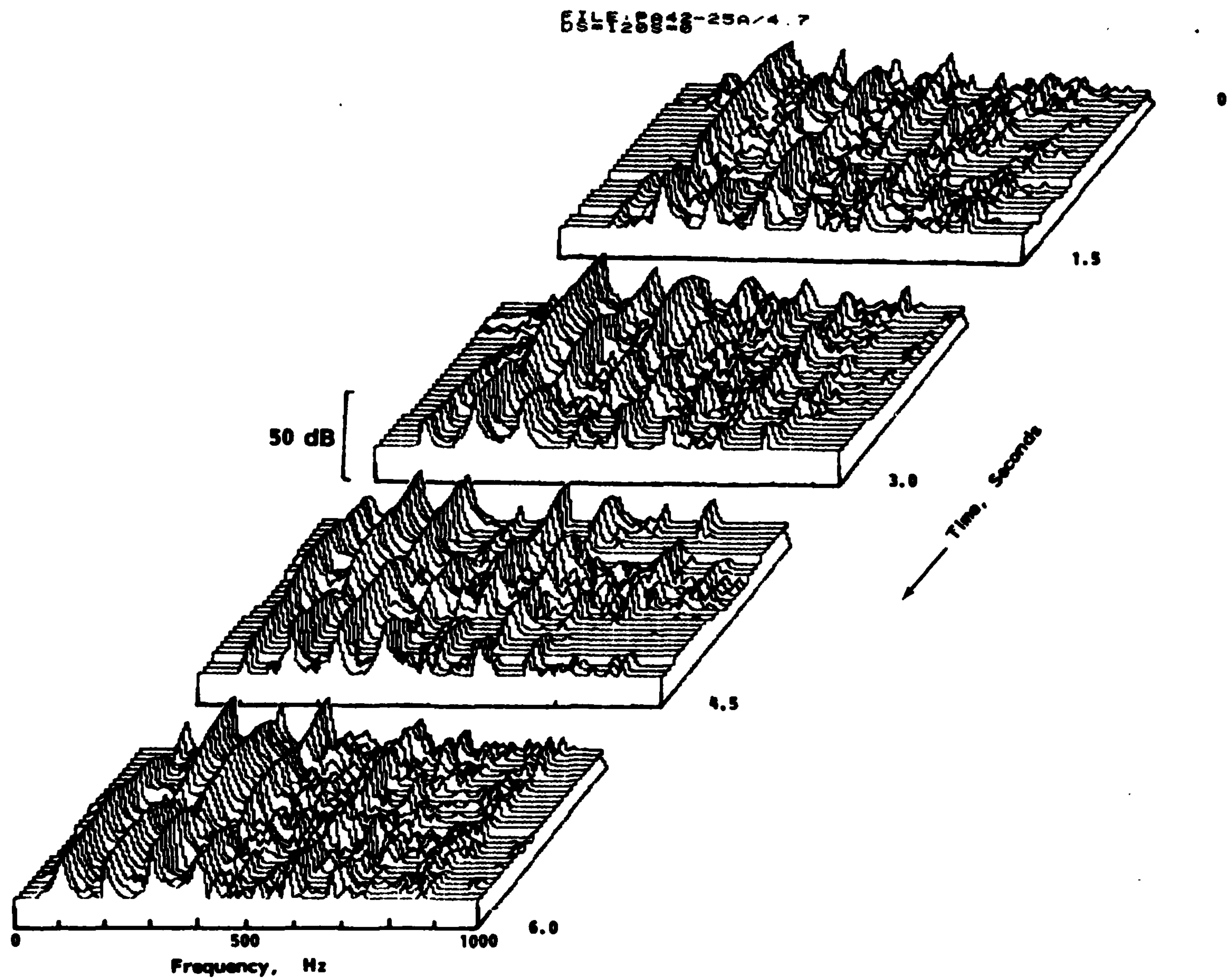


FIGURE A.17 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR TAKE-OFF OF PIPER PA-42 CHEYENNE (RUN 25)

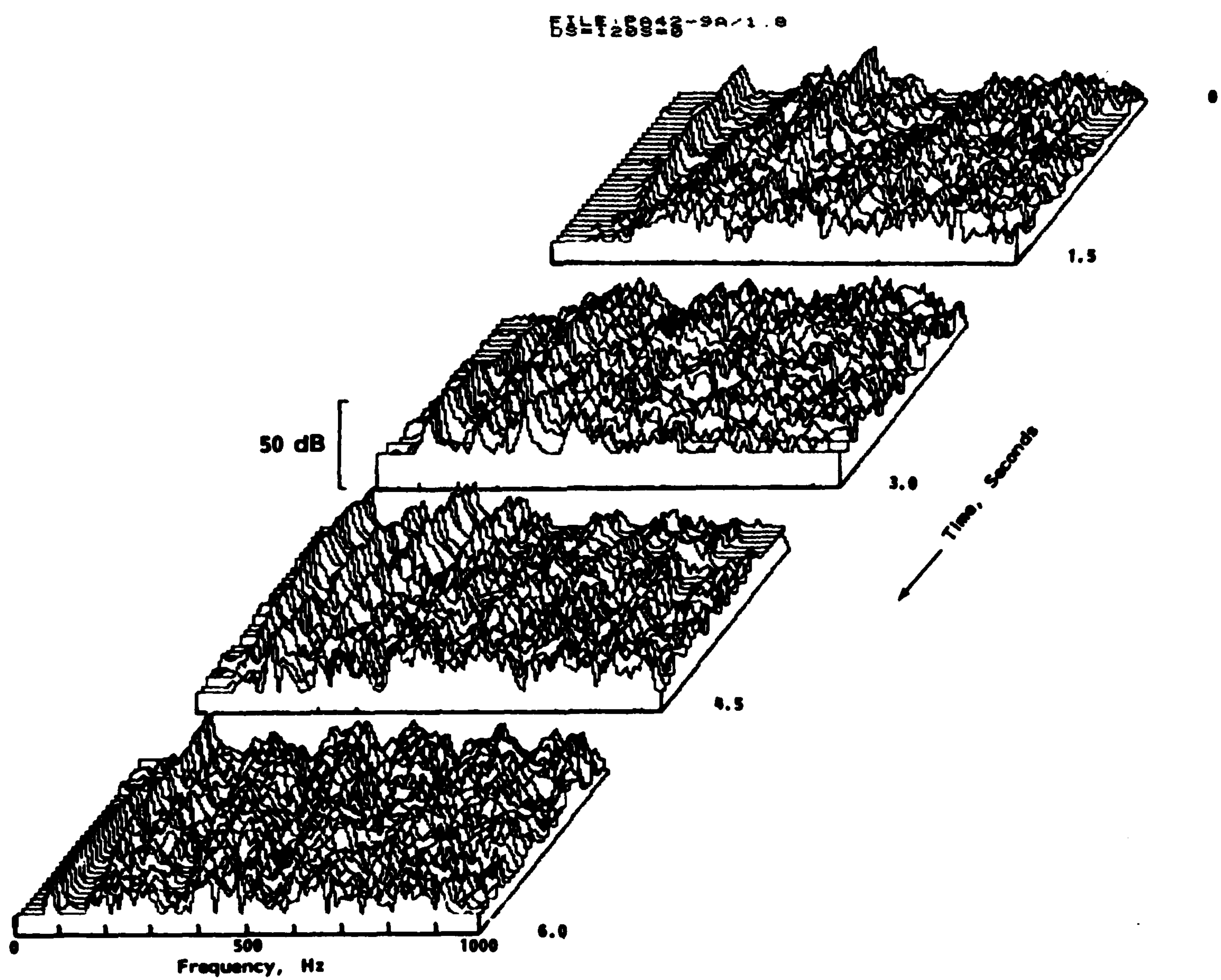


FIGURE A.18 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF PIPER PA-42 CHEYENNE (RUN 9)

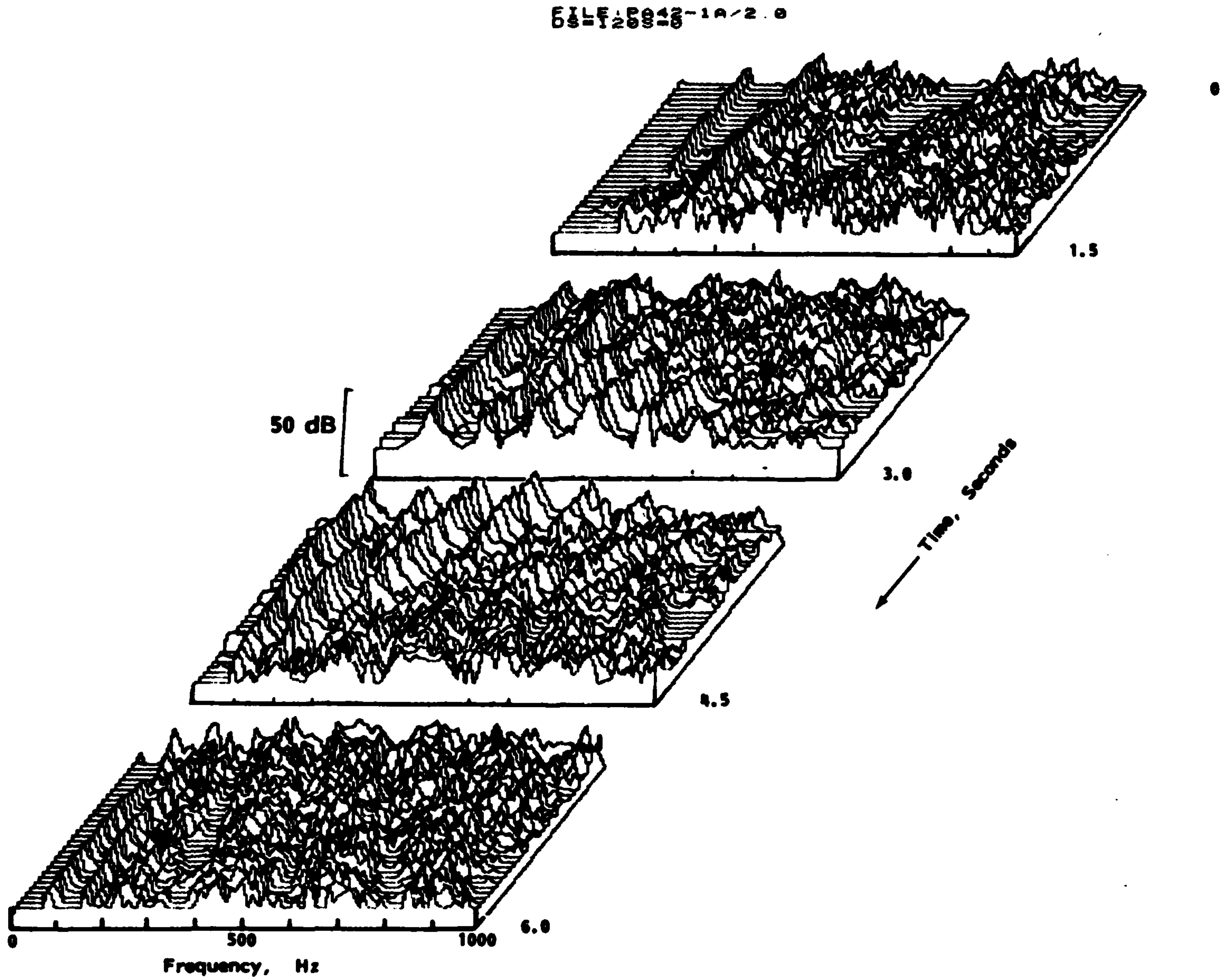


FIGURE A.19 SEQUENTIAL A-WEIGHTED SOUND LEVEL SPECTRA FOR FLY-OVER OF PIPER PA-42 CHEYENNE (RUN 1)

APPENDIX B
A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA

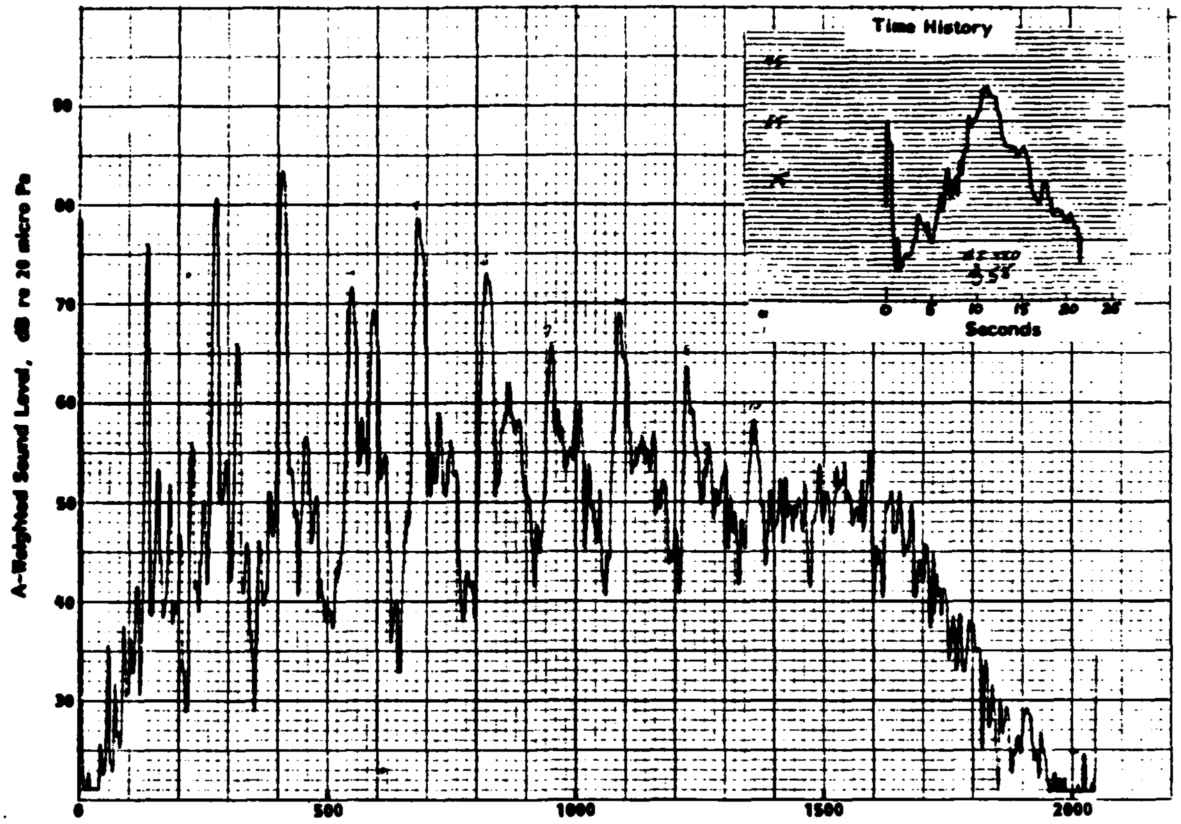
APPENDIX B
A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA

A-weighted sound level time histories of the selected take-off and flyover runs were obtained by replaying the recorded signals through the A-weighting network of a B&K Type 2203 Precision Sound Level Meter (unless the recorded signal was already A-weighted) and plotting the resulting sound level on a B&K Type 2305 Graphic Level Recorder. The paper speed for the level recorder was 3 mm/sec and the pen speed 80 mm/sec. No attempt was made to simulate the slow response of the sound level meter when plotting the time histories.

Narrowband spectra for the A-weighted sound levels were obtained by replaying the signal through the A-weighting network of a B&K Type 2203 Precision Sound Level Meter into a Spectral Dynamics SD360 Digital Signal Processor. The data reduction was performed at the time associated with maximum A-weighted sound level, and the average time was kept to a minimum in order that the frequencies of the propeller harmonic components in the spectra would not be blurred by Doppler effects. Thus, the averaging time ranged from 0.50 sec to 1.0 sec. The lower limit on the averaging process was dictated by the time period associated with one data sample. The spectra were obtained for the frequency range zero to 2000 Hz, and the frequency resolution was 2 Hz.

Narrowband spectra and time histories for the A-weighted sound levels are shown in Figures B.1 through B.16. The spectra show a falloff in level at frequencies above 1600 Hz. However, this falloff is caused by the anti-aliasing filters in the Digital Signal Processor and it is not a characteristic of the basic spectrum.

(a) Run 2



(b) Run 6

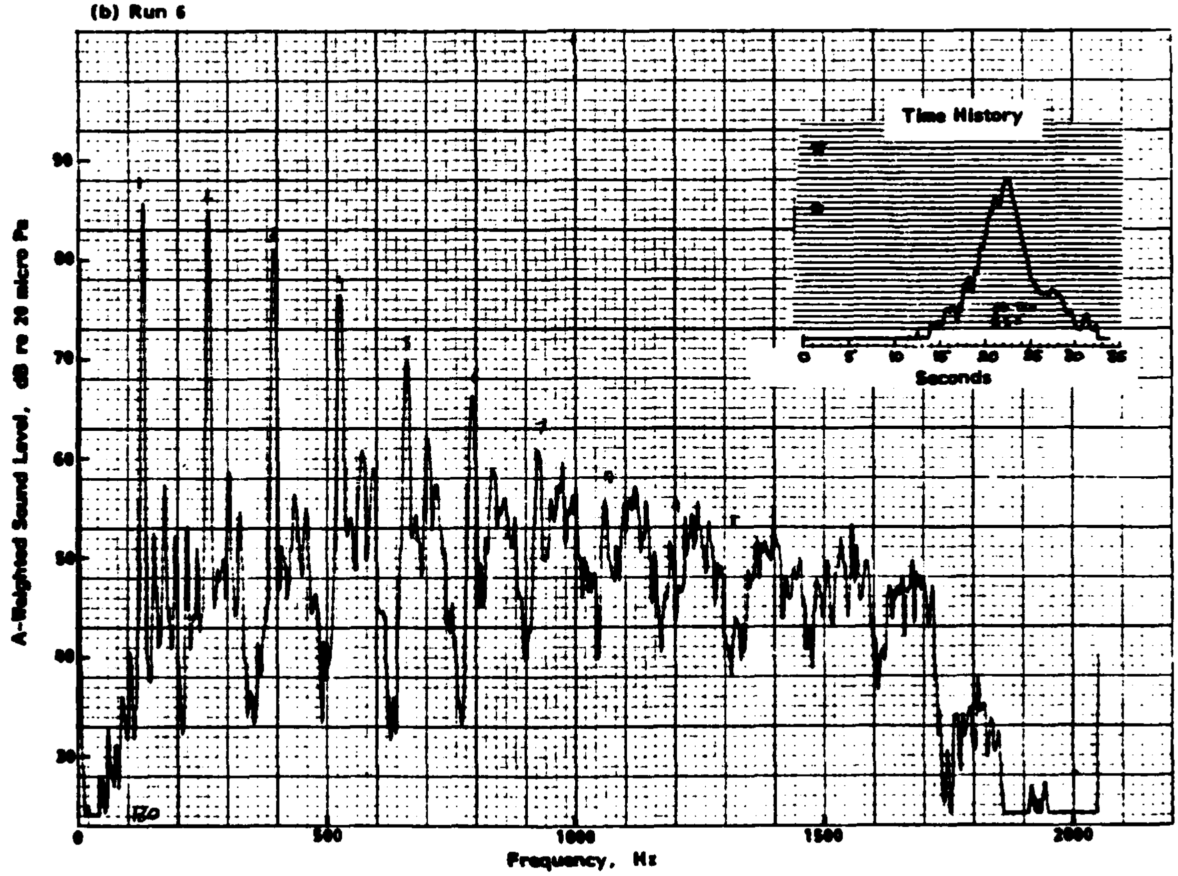


FIGURE B.1 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF BEECH B58P BARON

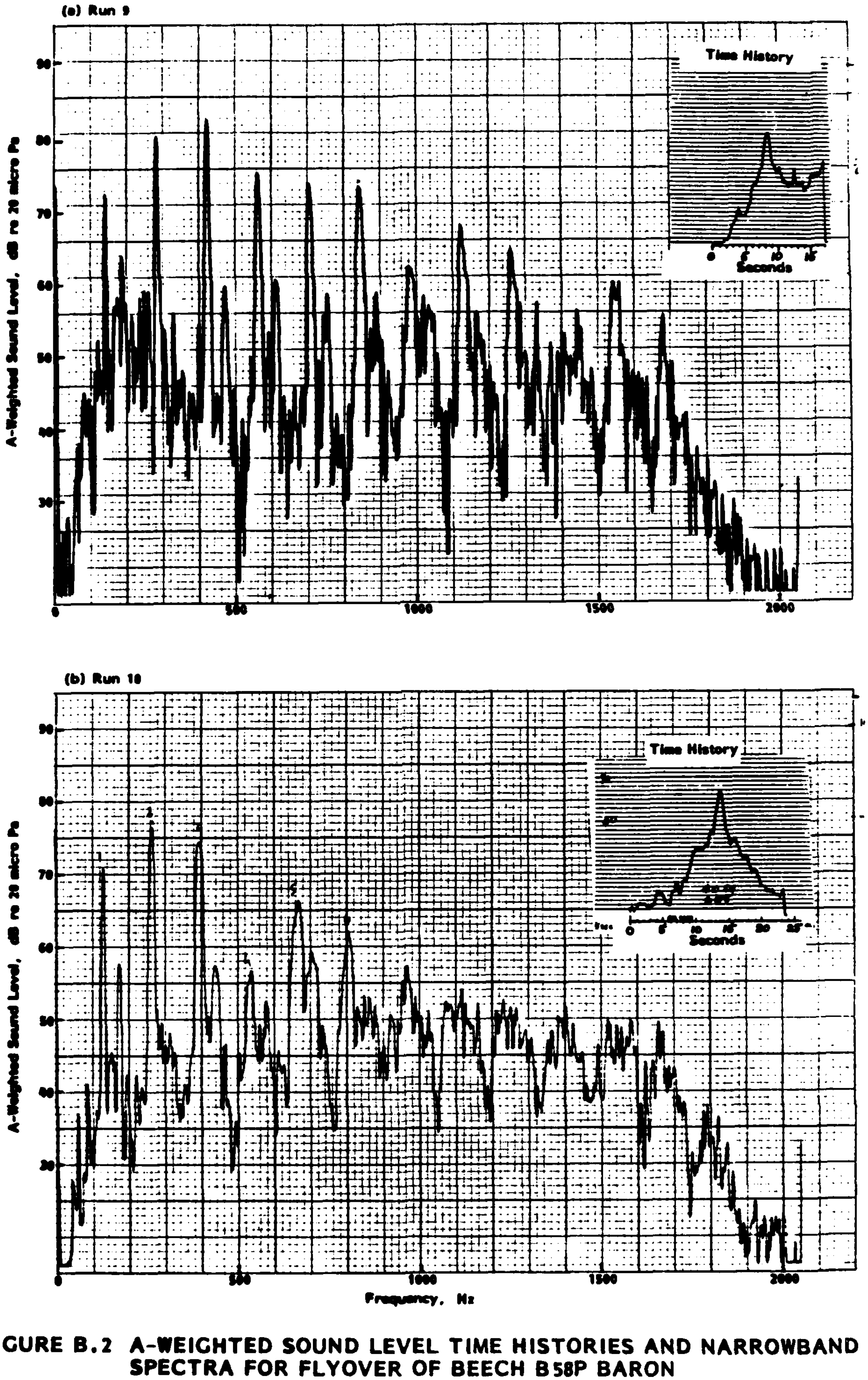
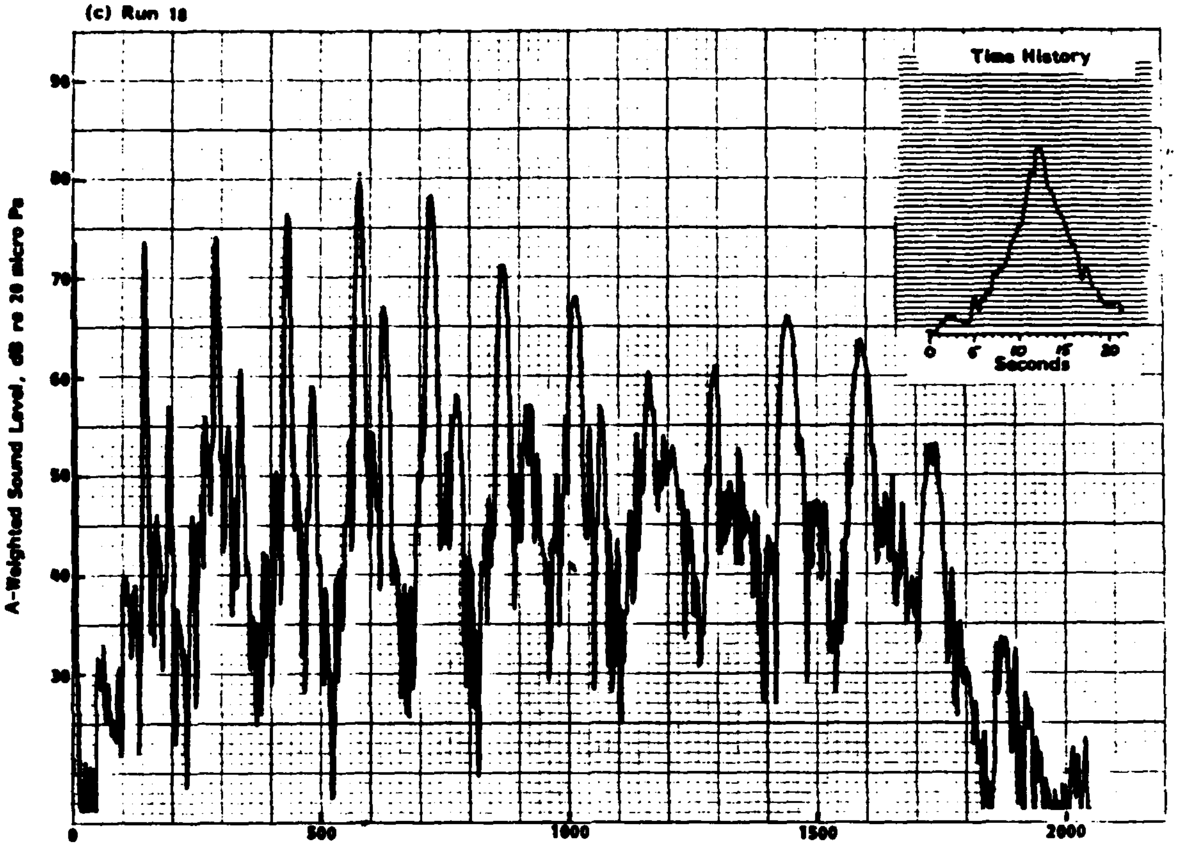


FIGURE B.2 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF BEECH B58P BARON



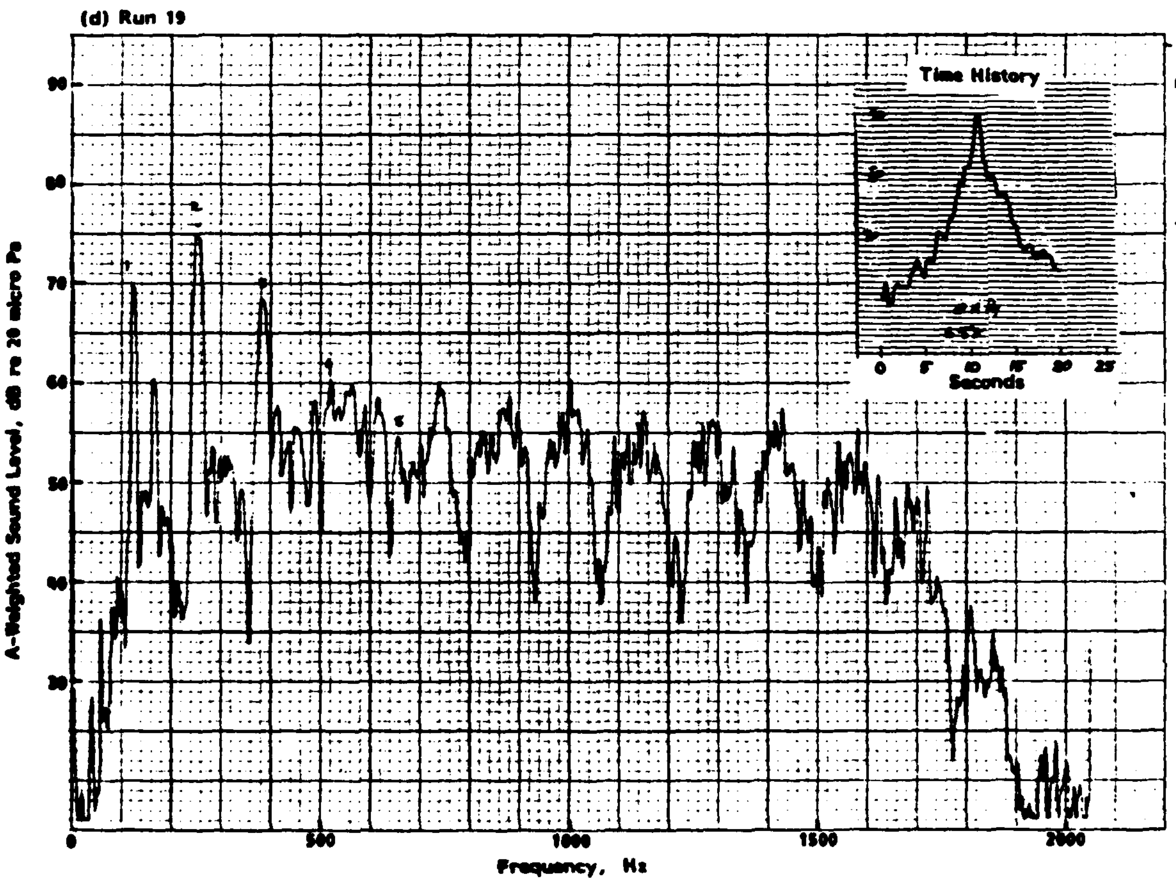


FIGURE B.2 CONTINUED

(e) Run 26

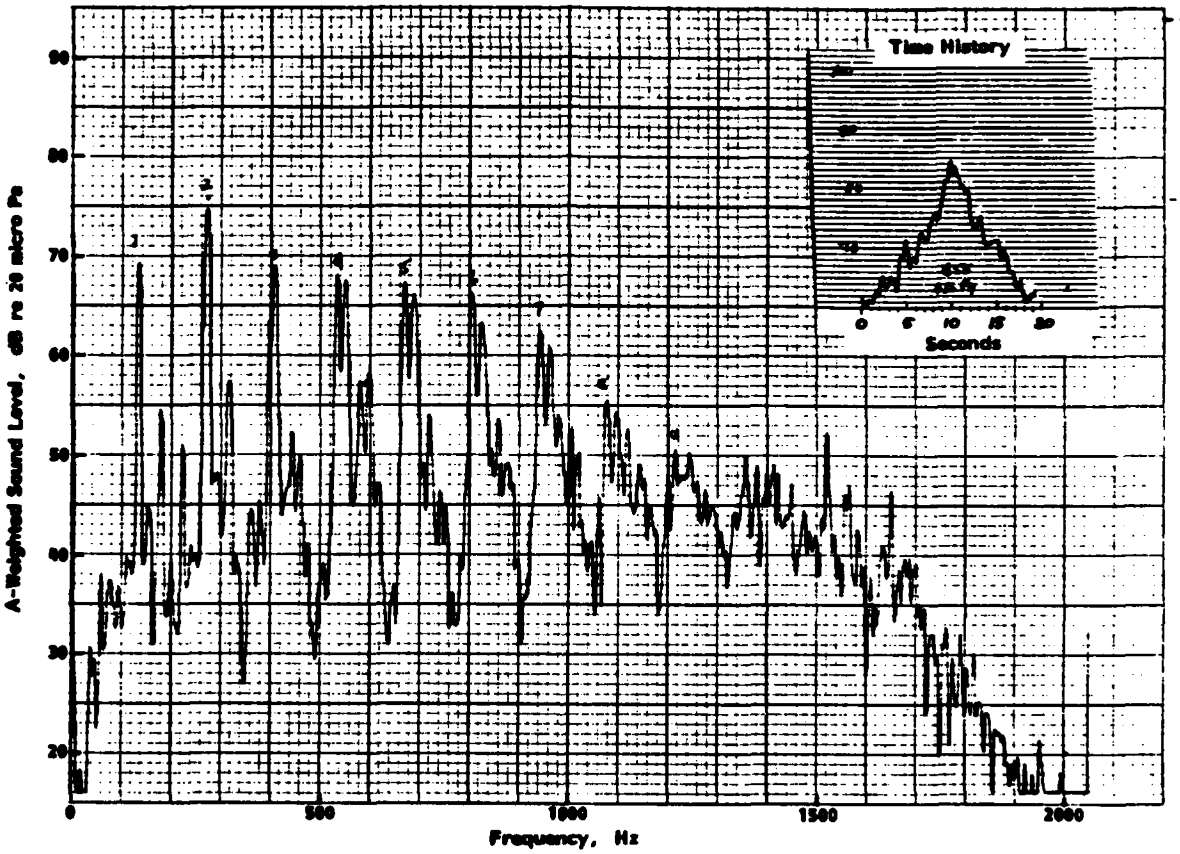
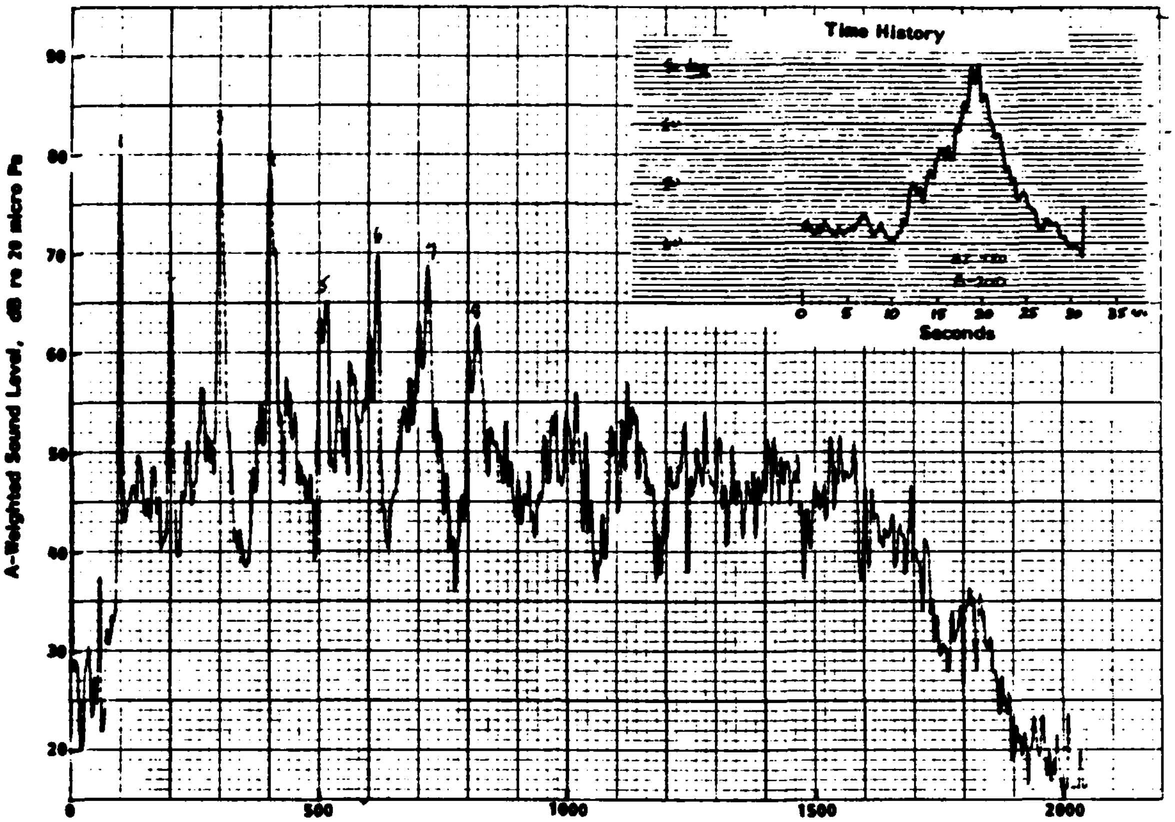


FIGURE B.2 CONTINUED

(a) Run 2



(b) Run 3

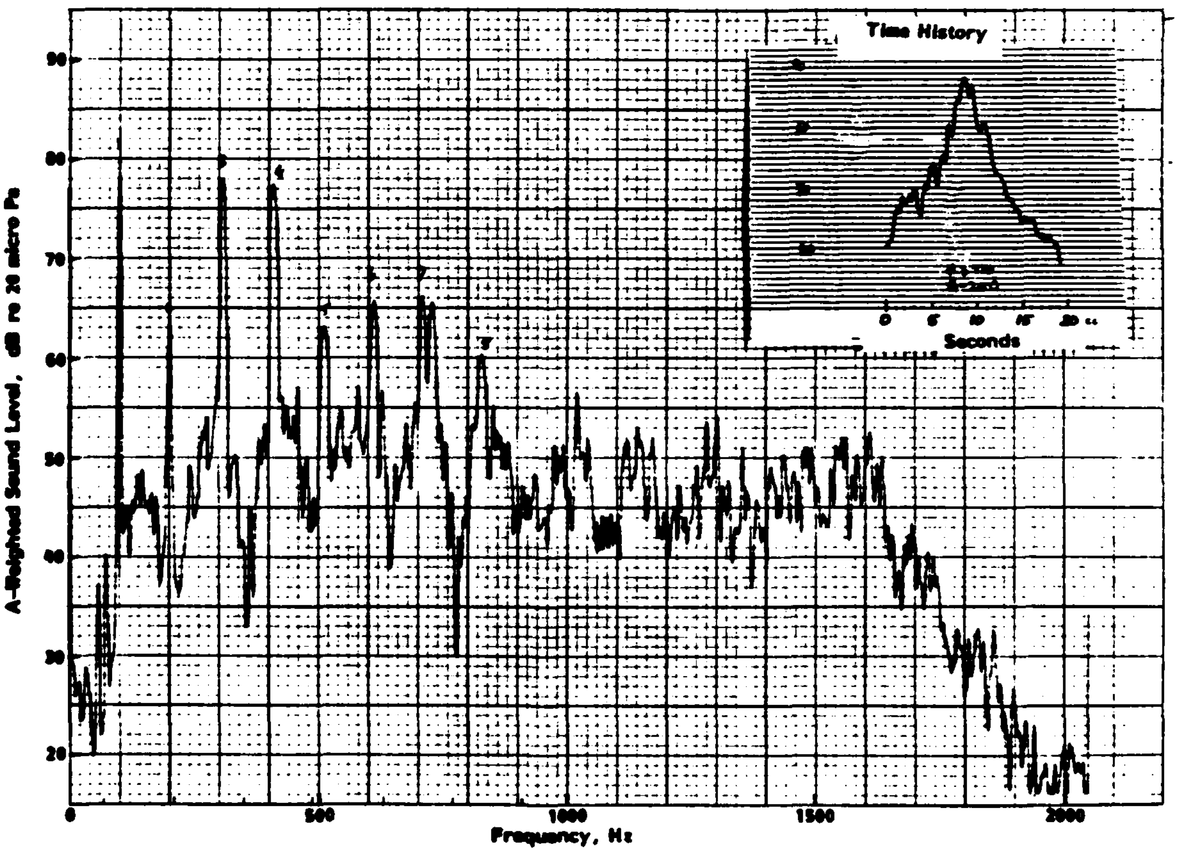
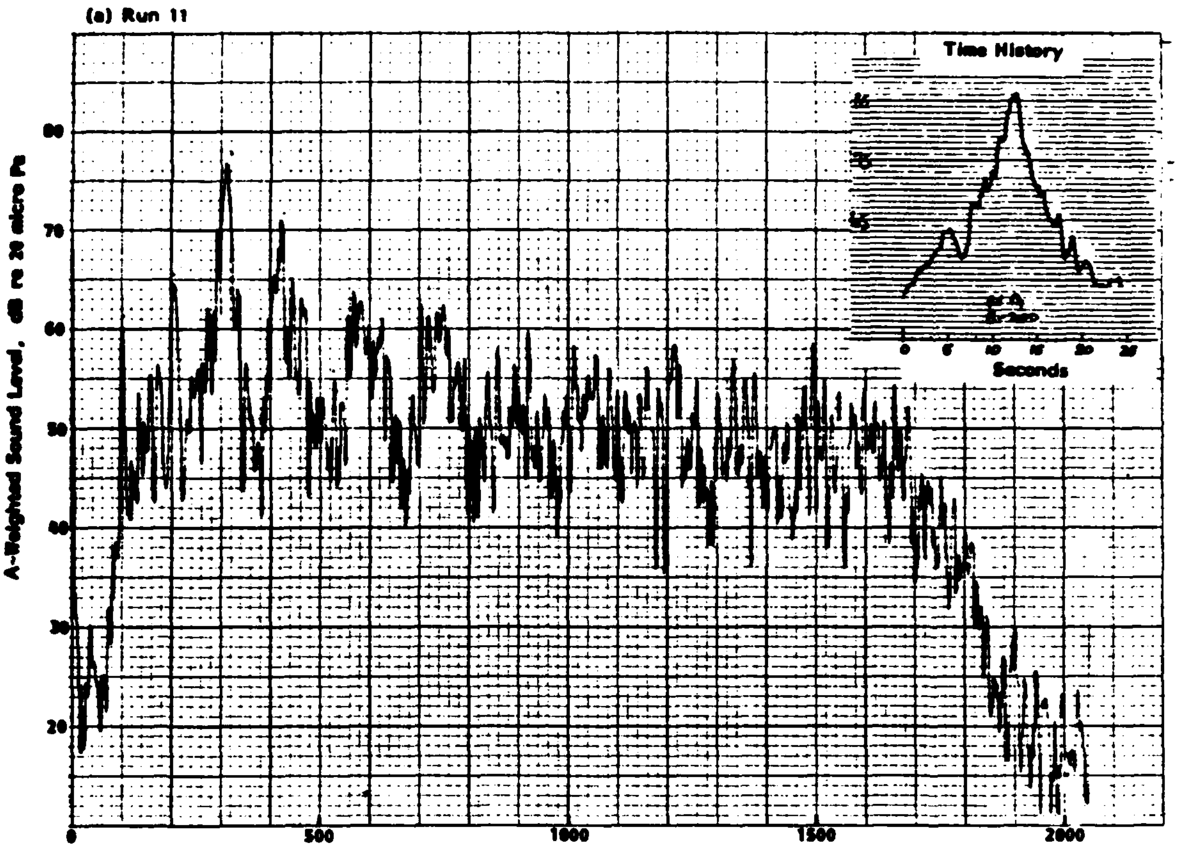


FIGURE B.3 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF BEECH B200 SUPER KING AIR



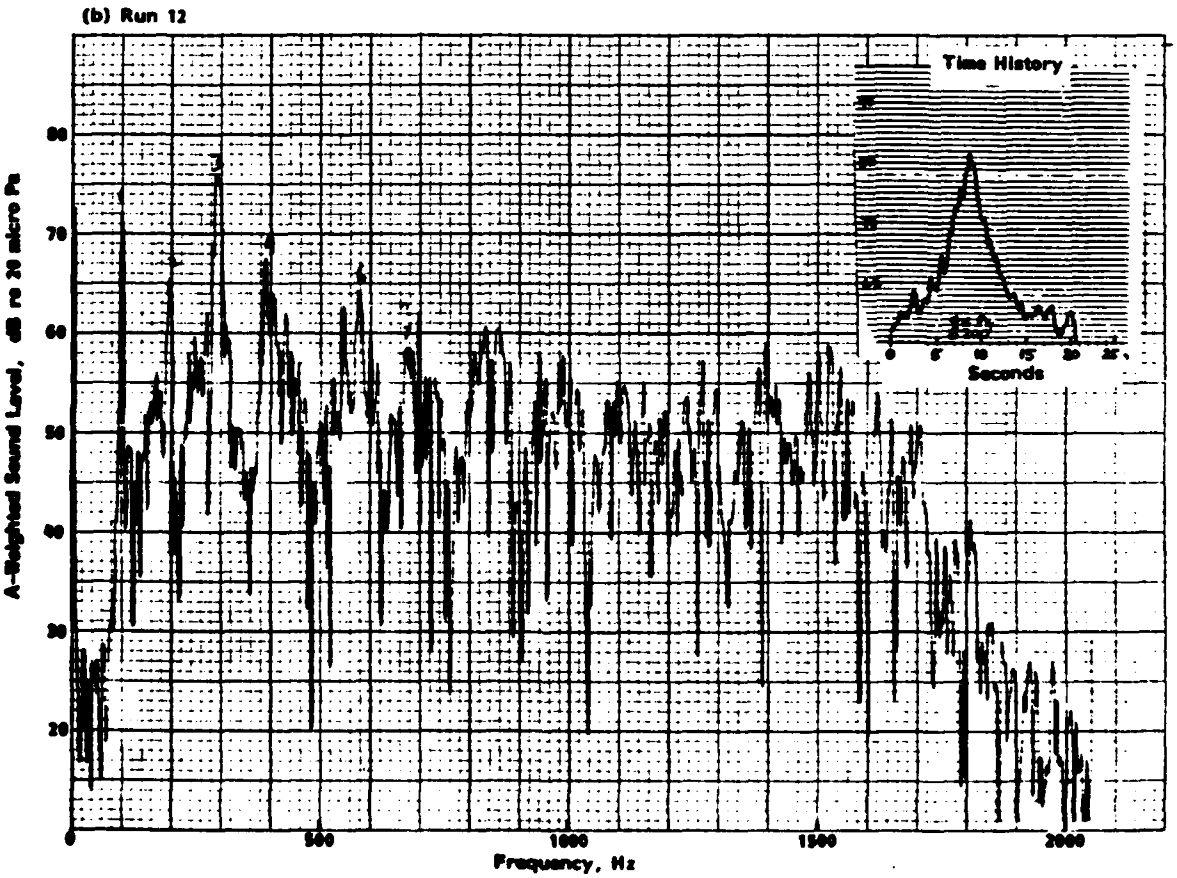
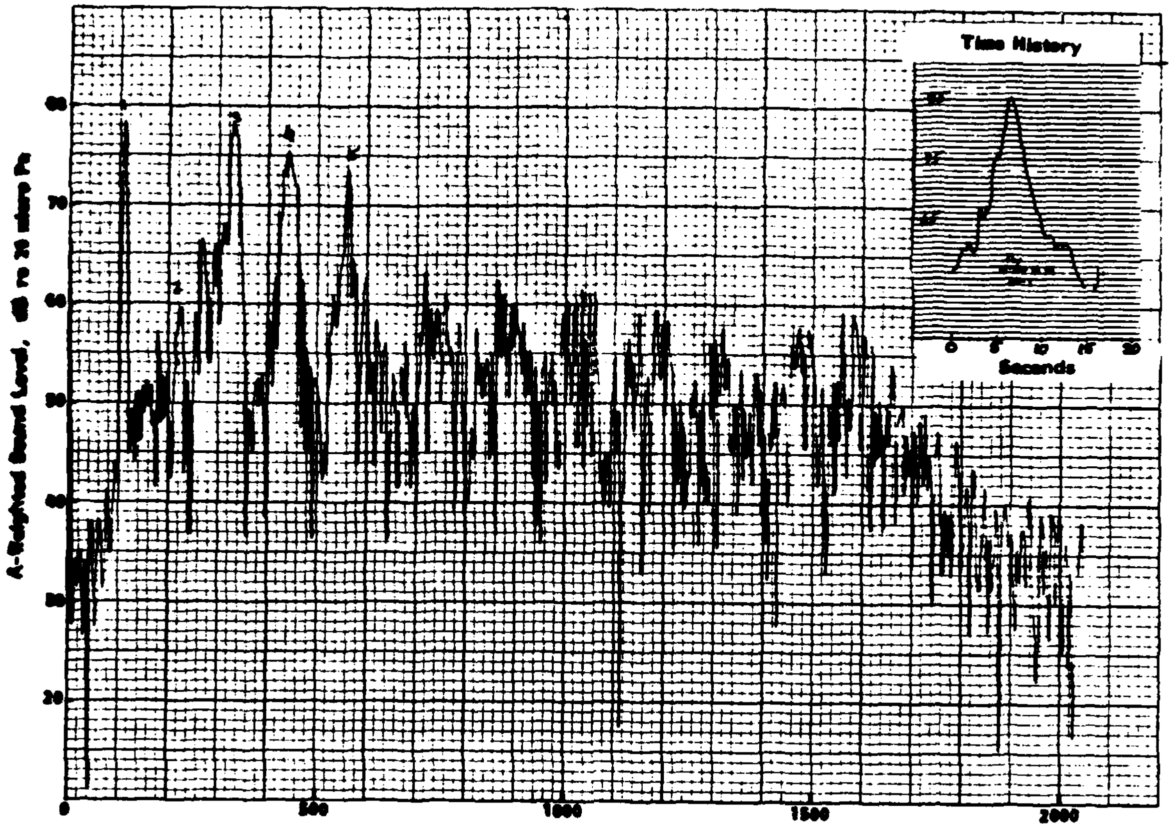


FIGURE B.4 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF BEECH B200 SUPER KING AIR

(c) Run 14



(d) Run 22

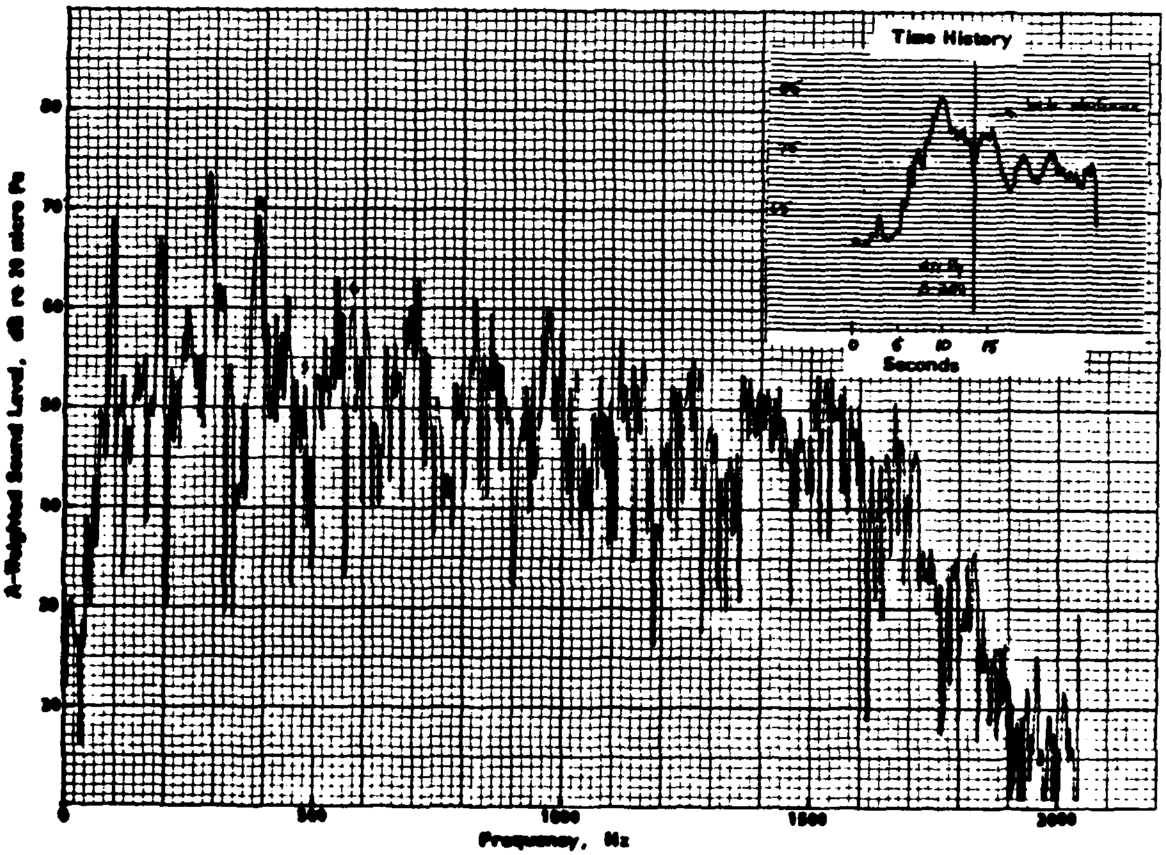


FIGURE B.4 CONTINUED

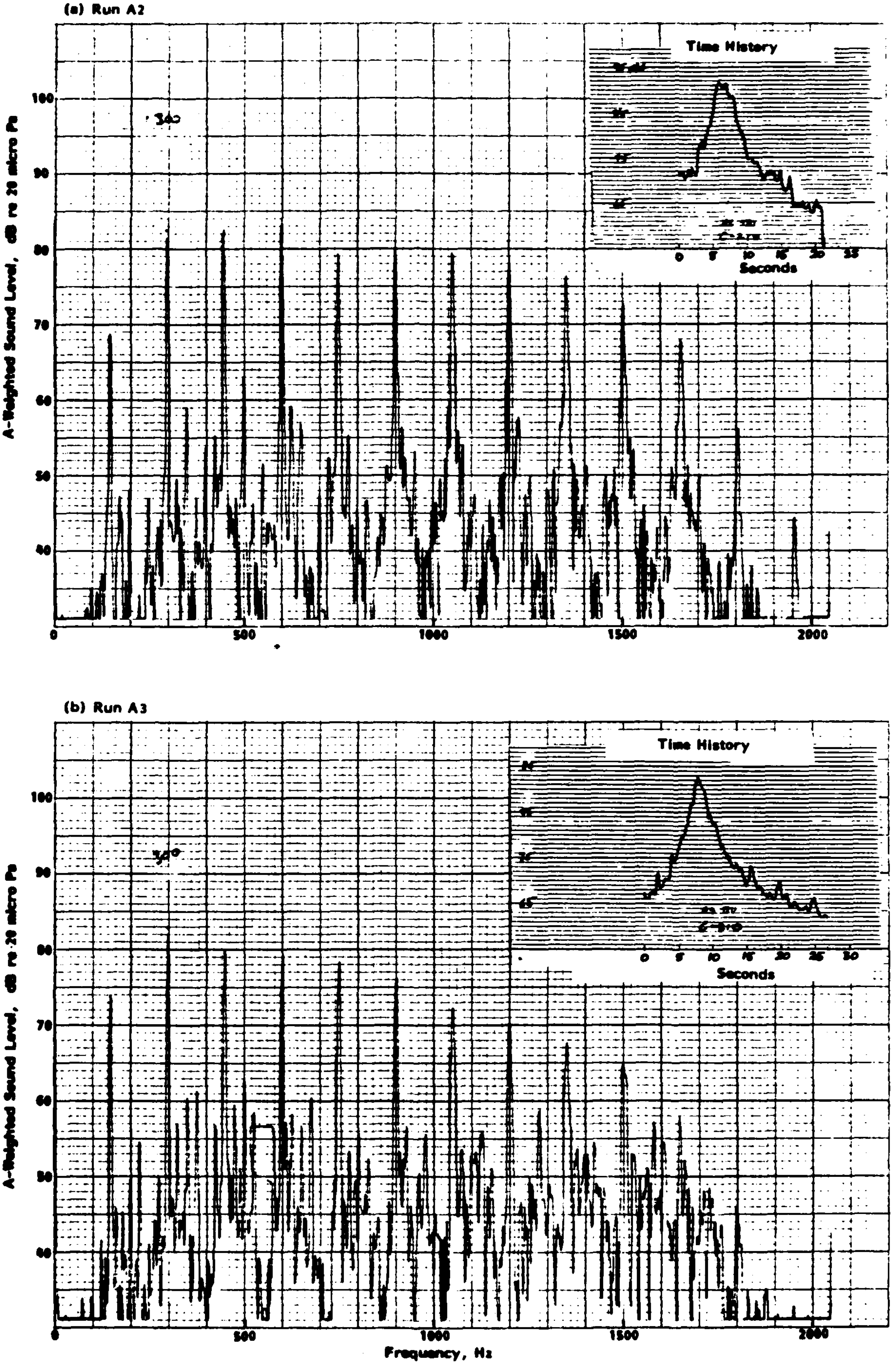
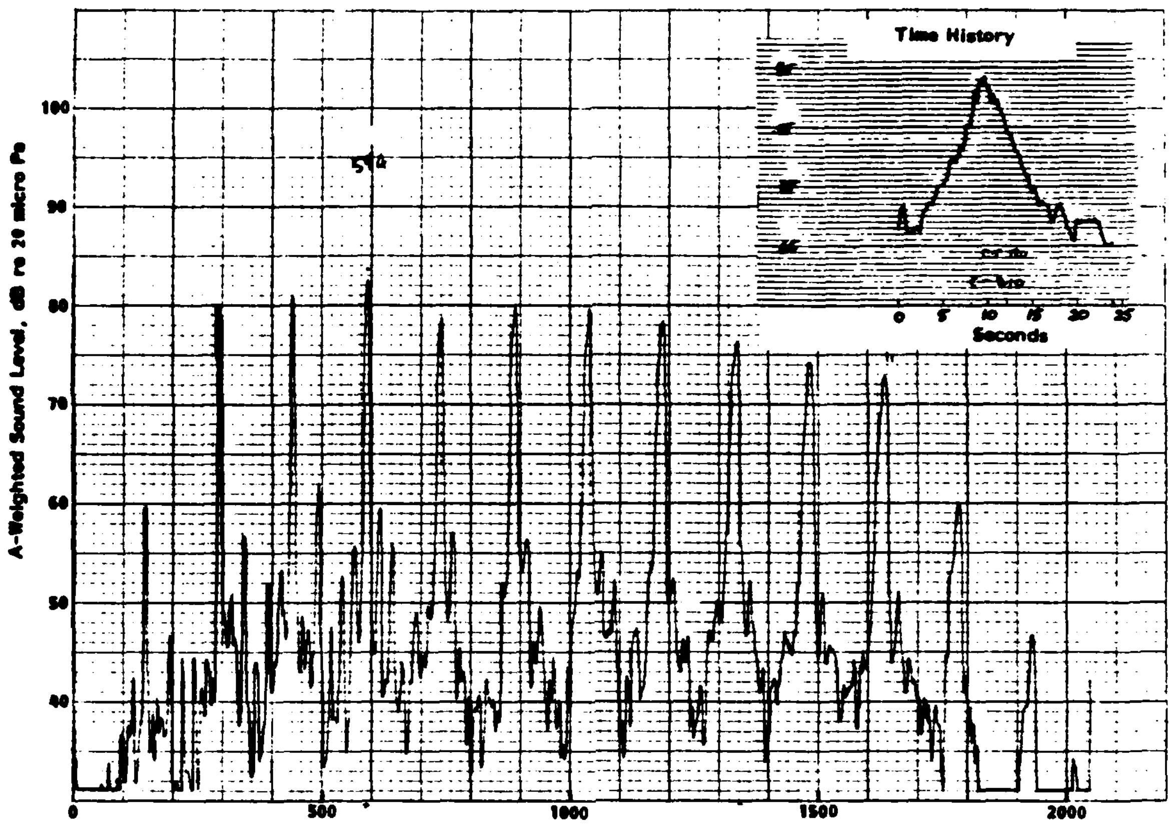


FIGURE B.5 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF CESSNA 210 CENTURION

(c) Run C5



(d) Run F11

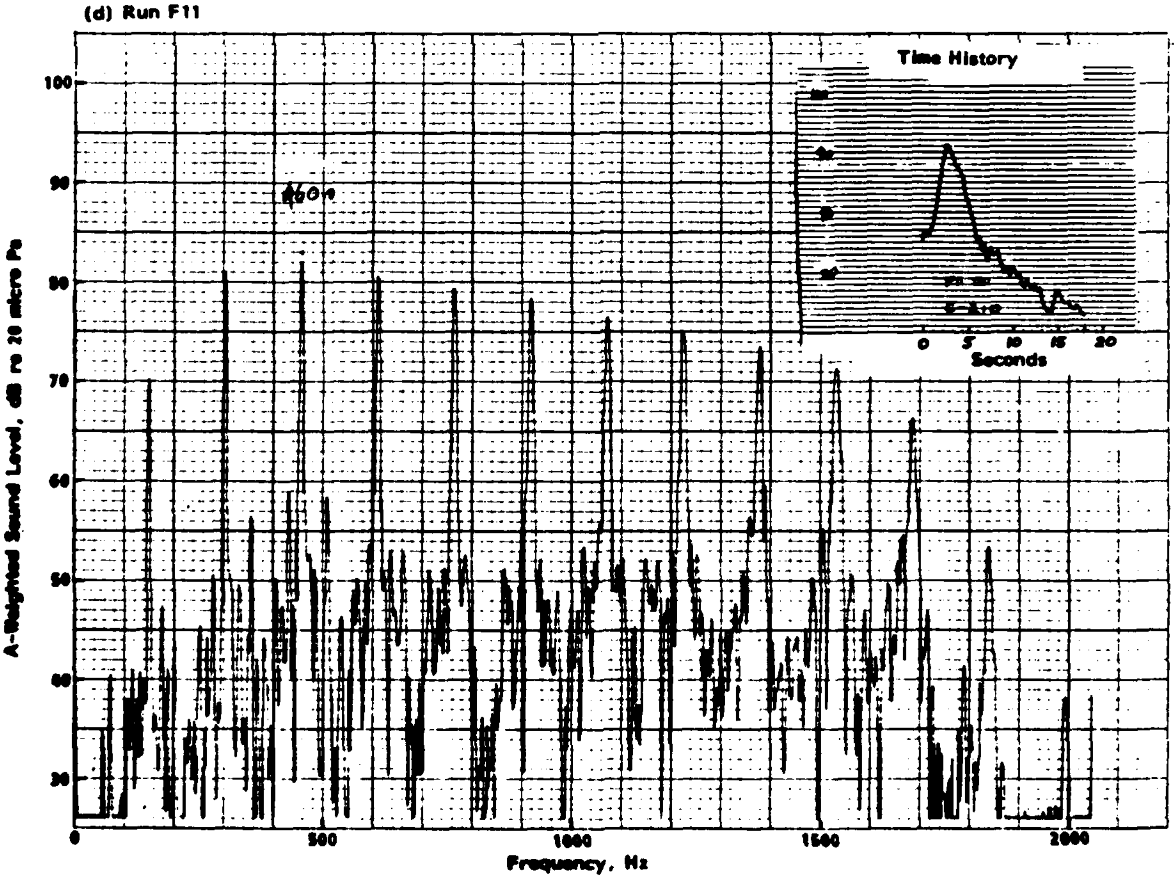


FIGURE B.5 CONTINUED

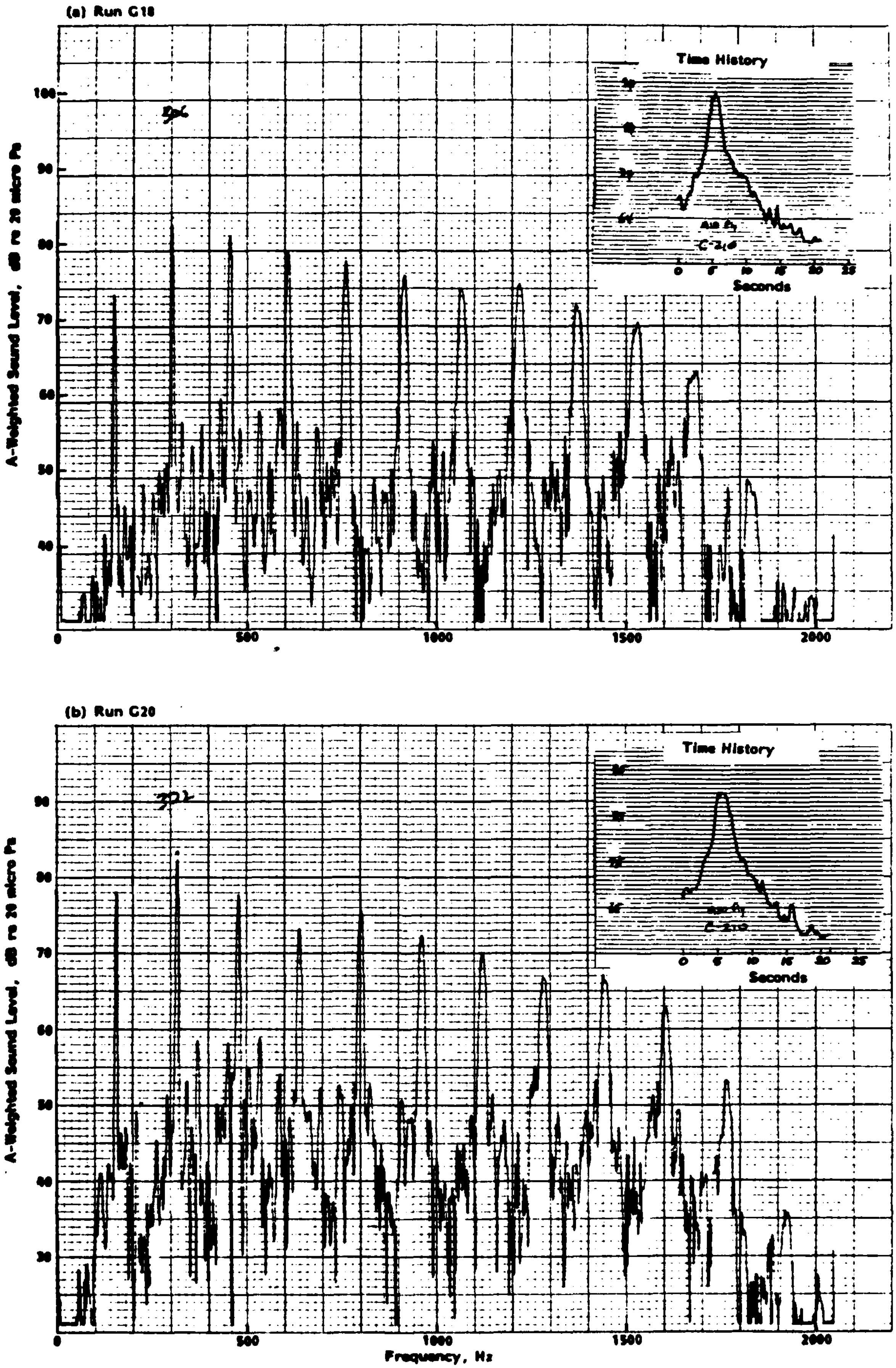


FIGURE B.6 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF CESSNA 210 CENTURION

(c) Run 126

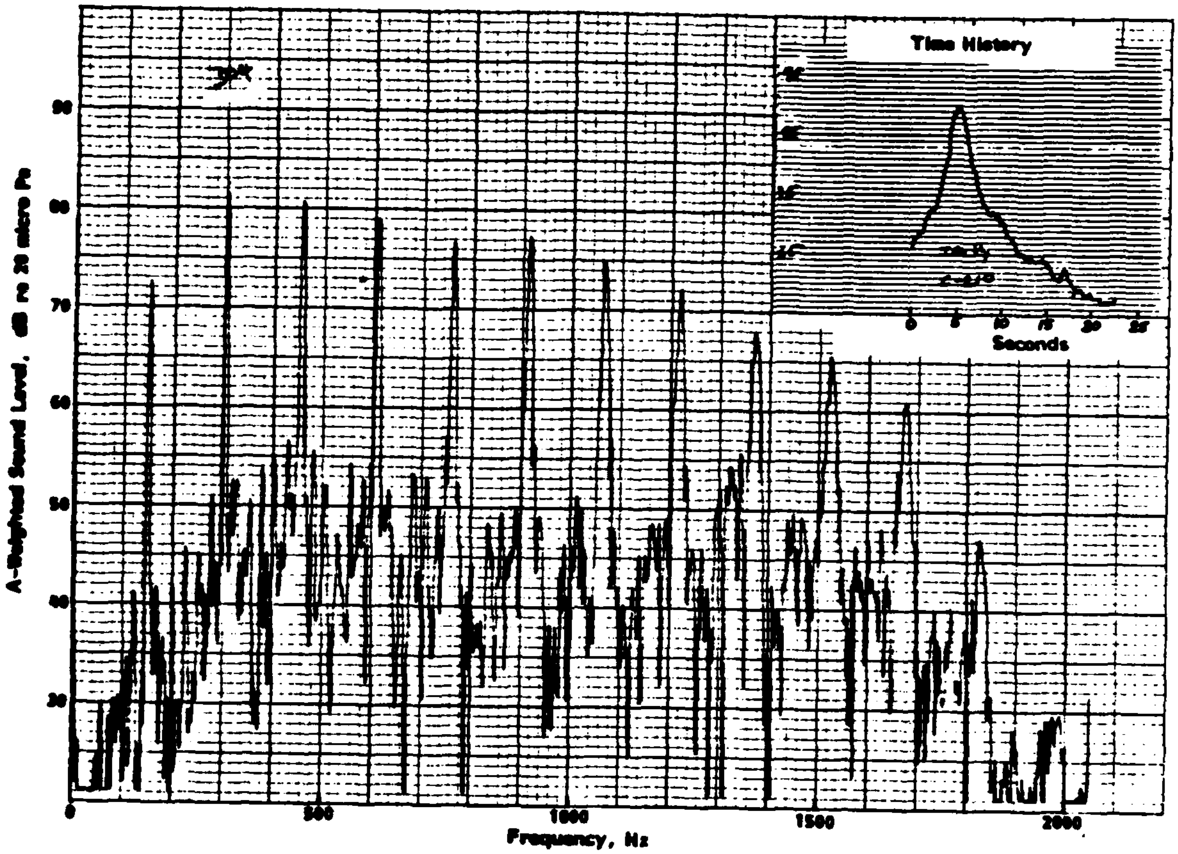


FIGURE B.6 CONTINUED

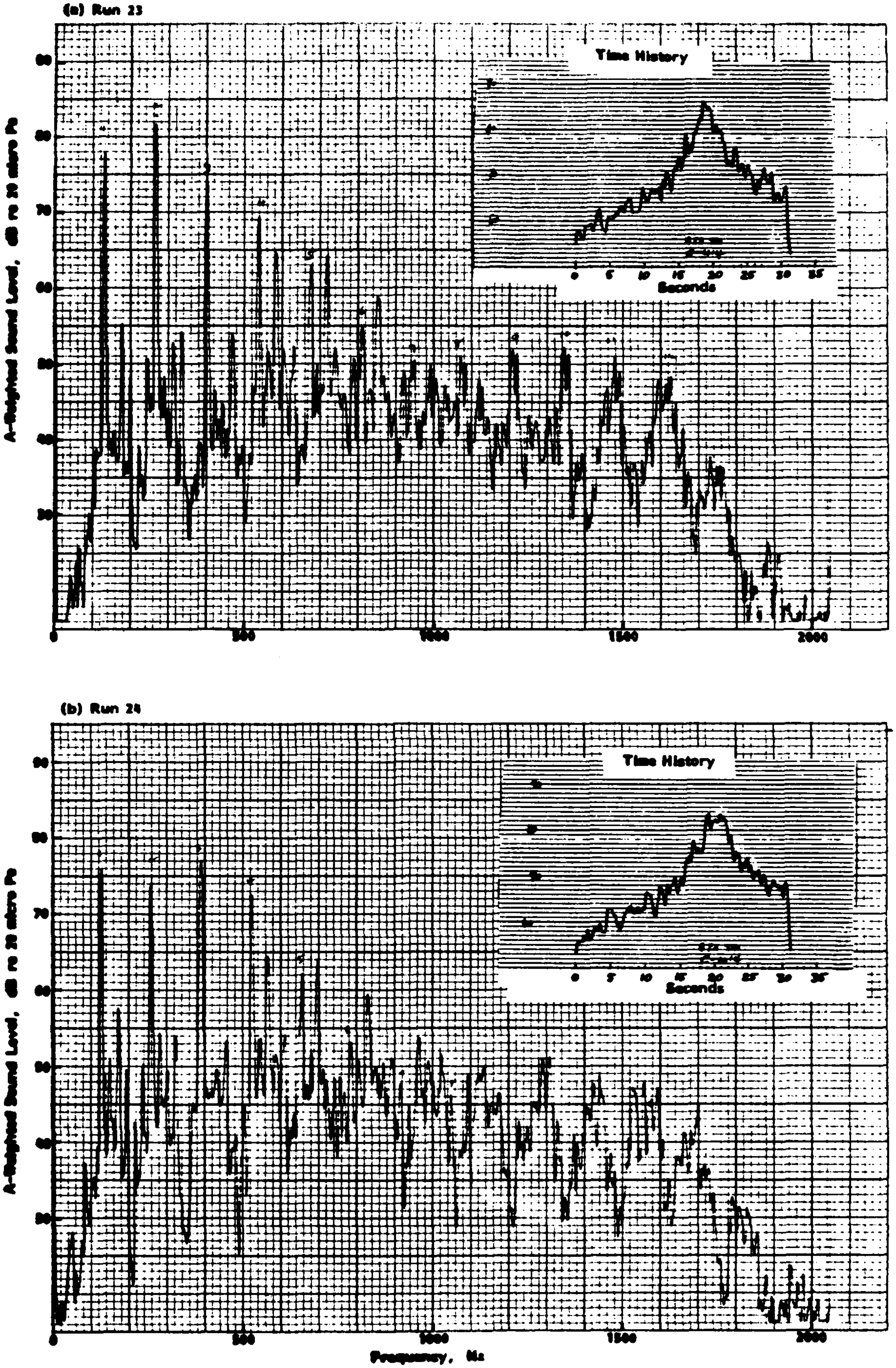


FIGURE B.7 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF CESSNA 414 CHANCELLOR

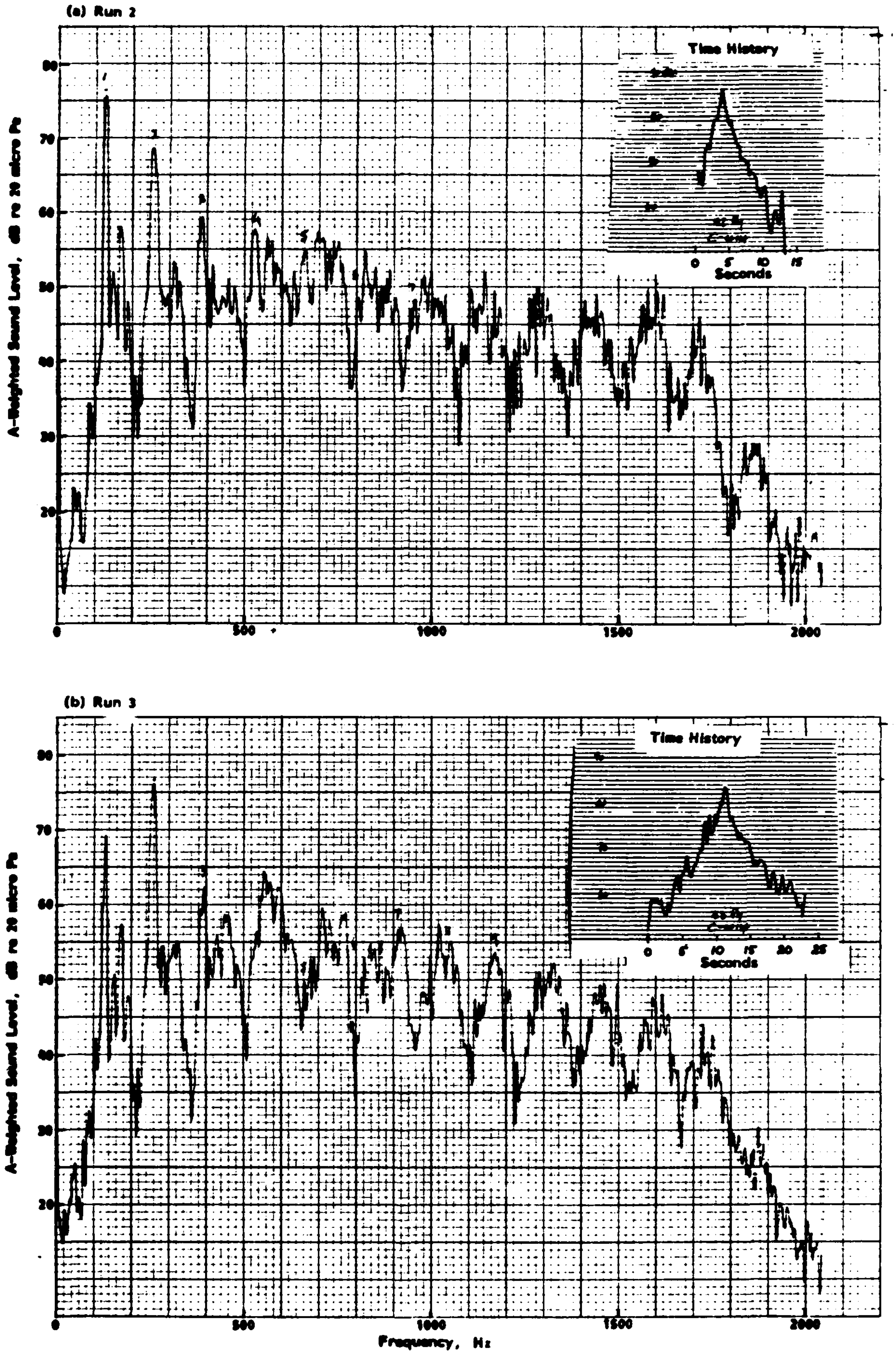


FIGURE B.8 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF CESSNA 414 CHANCELLOR

(c) Run 19

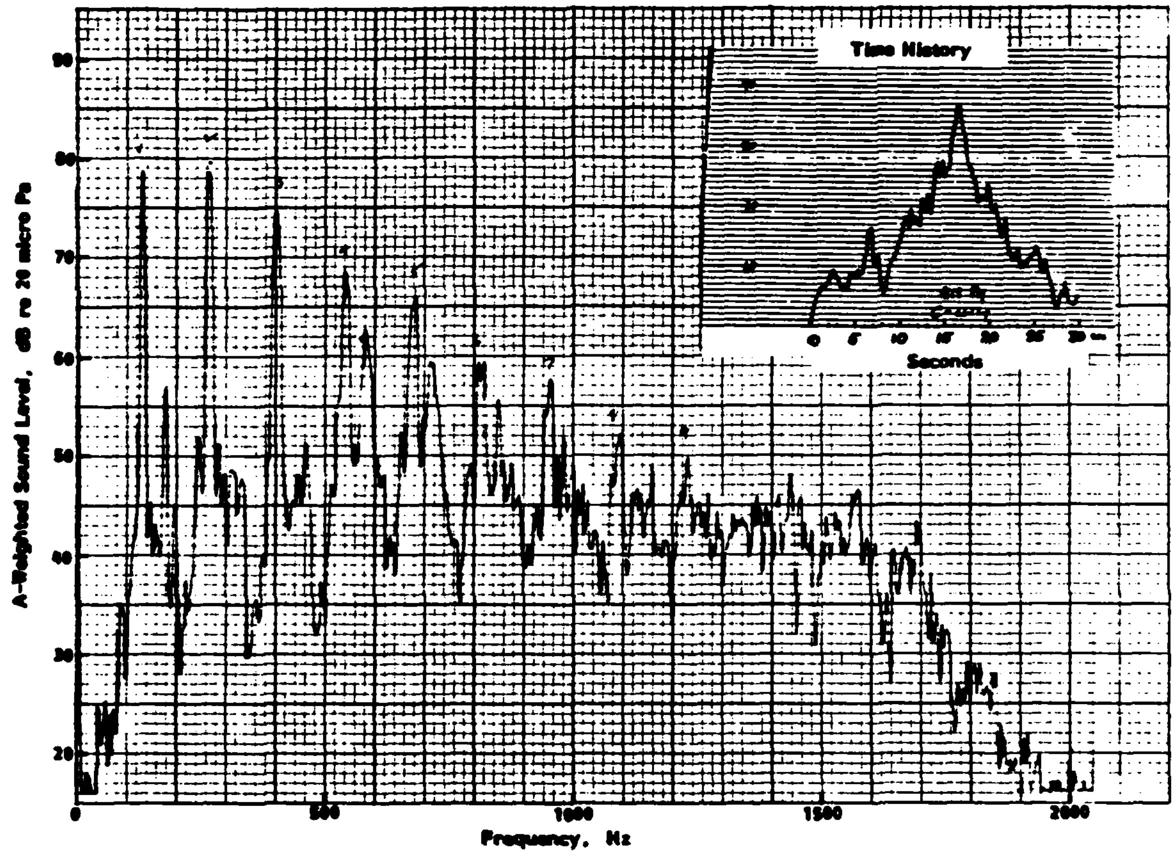


FIGURE B.8 CONTINUED

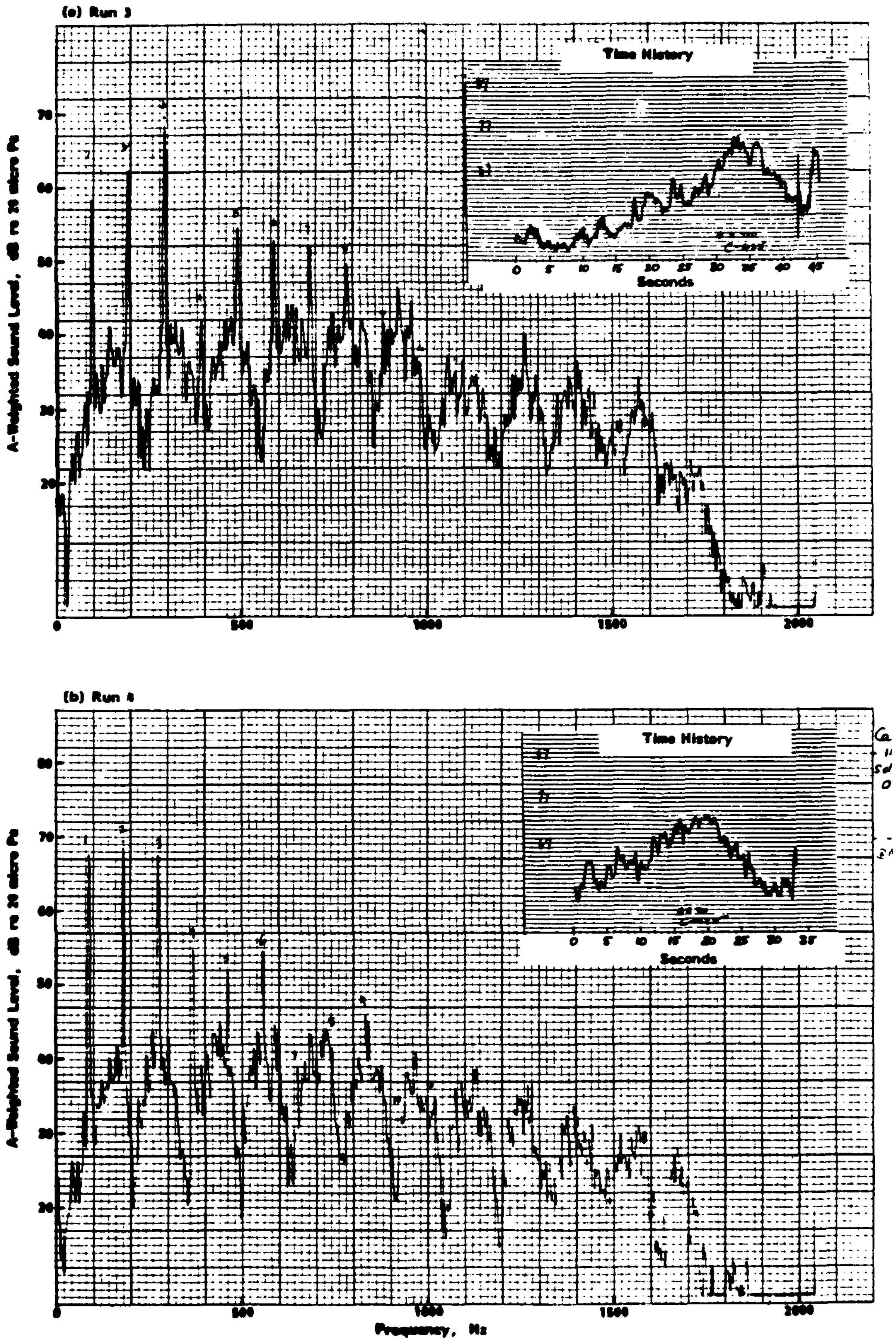
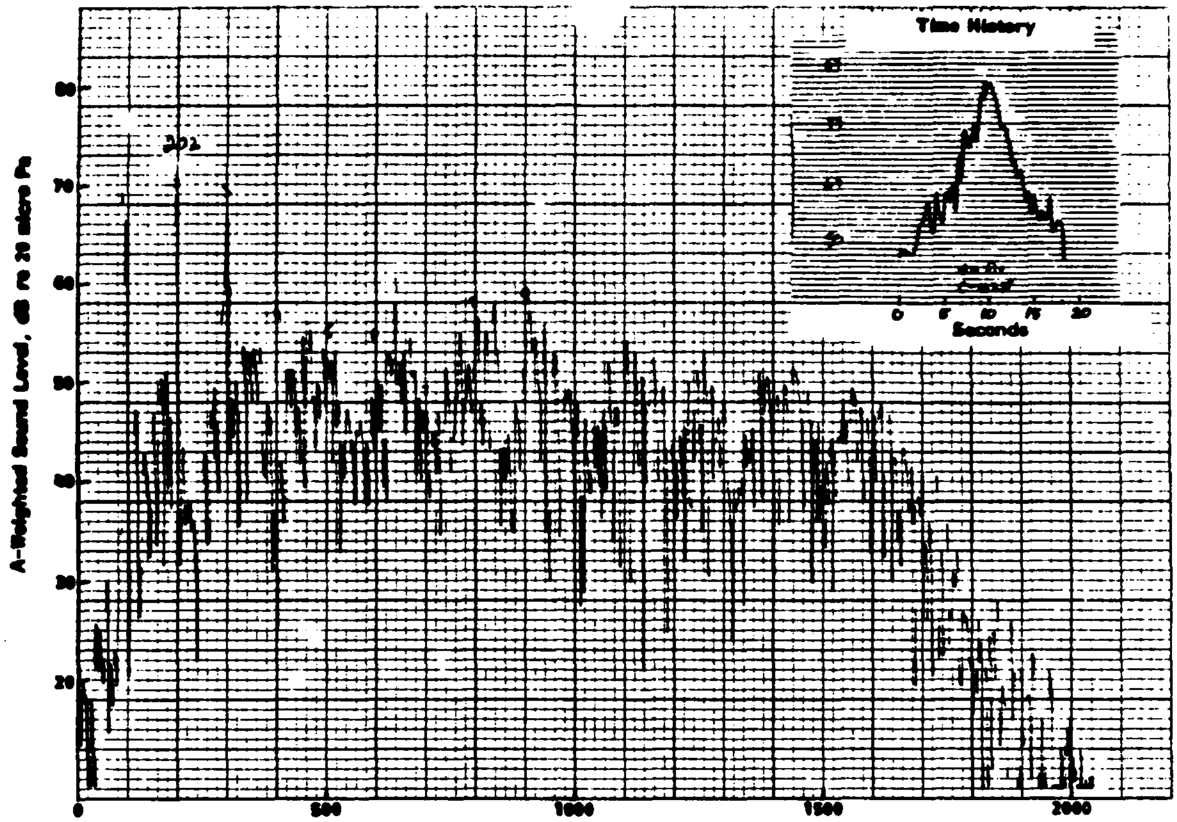


FIGURE B.9 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF CESSNA 425 CONQUEST 1

(a) Run 10



(b) Run 11

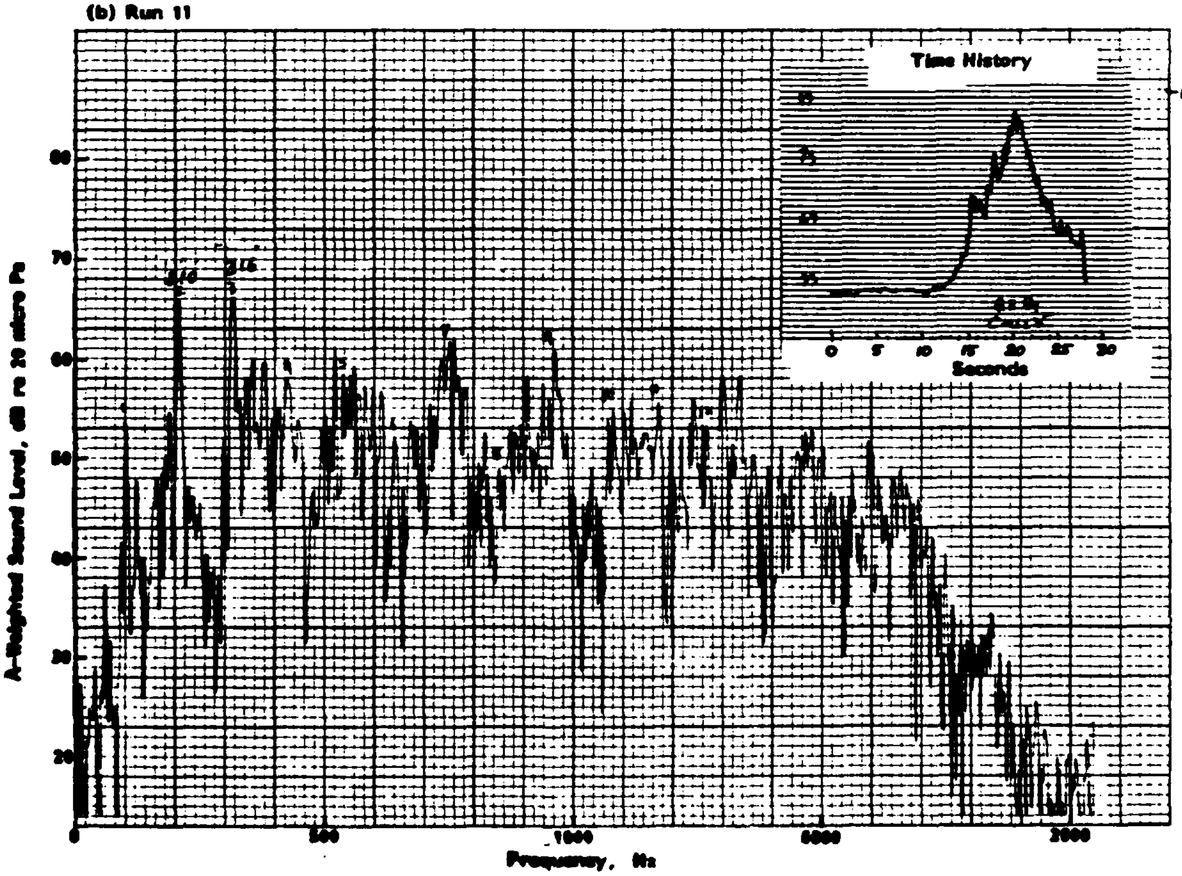
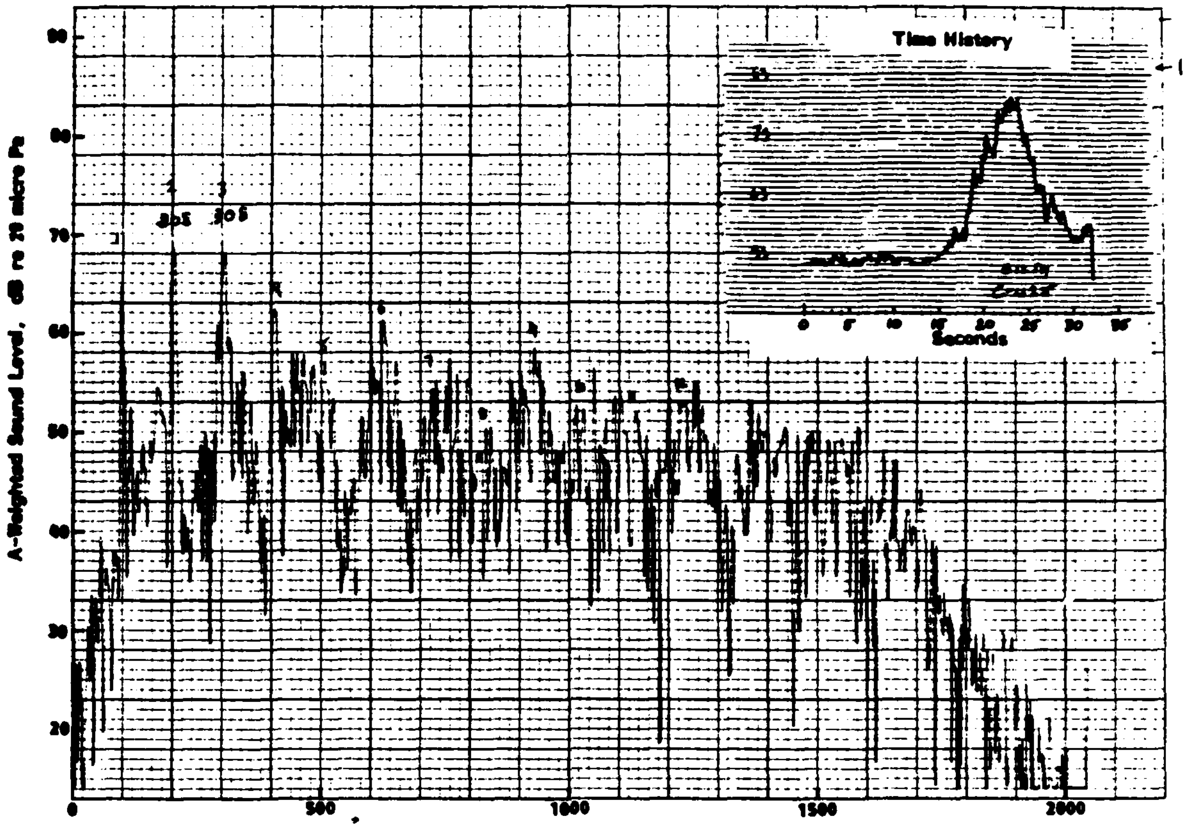


FIGURE B.10 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF CESSNA 425 CONQUEST 1

(c) Run 12



(d) Run 18

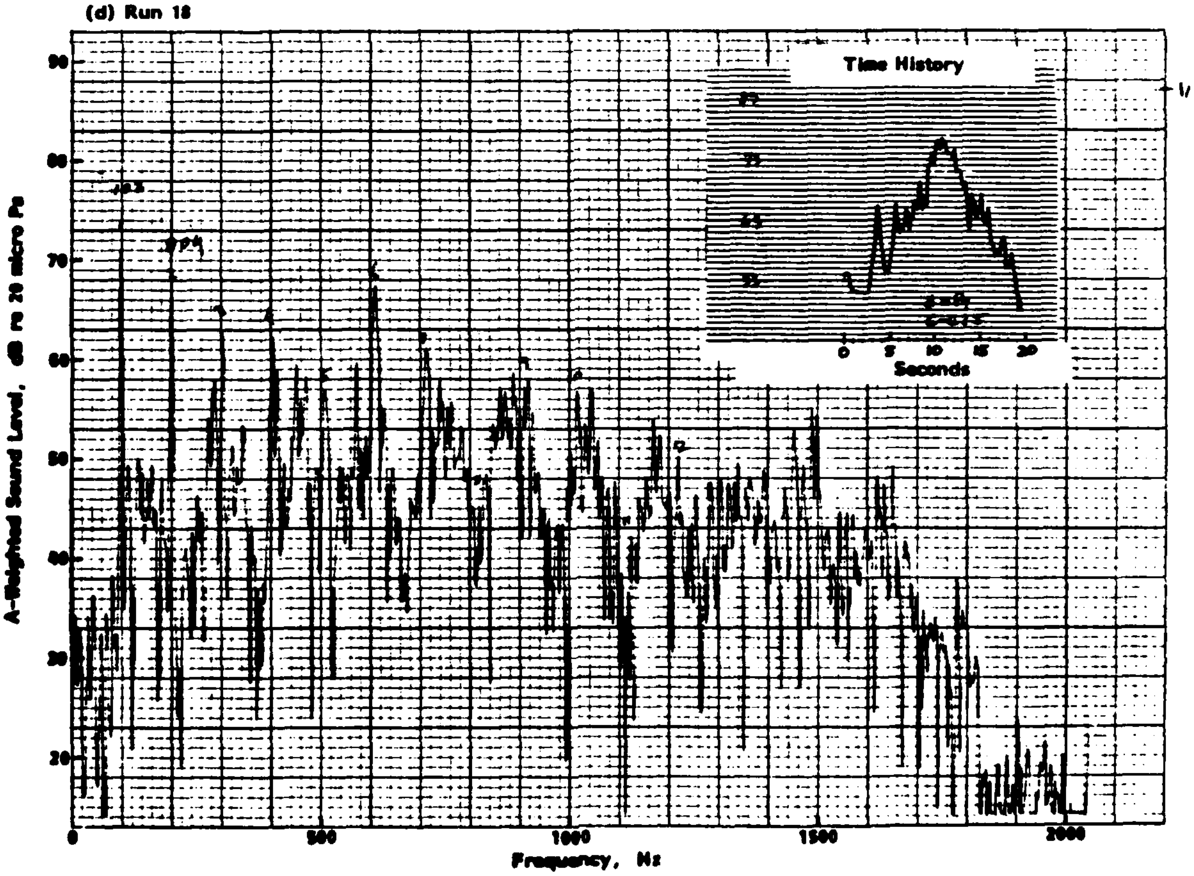


FIGURE B.10 CONTINUED

(a) Run 3

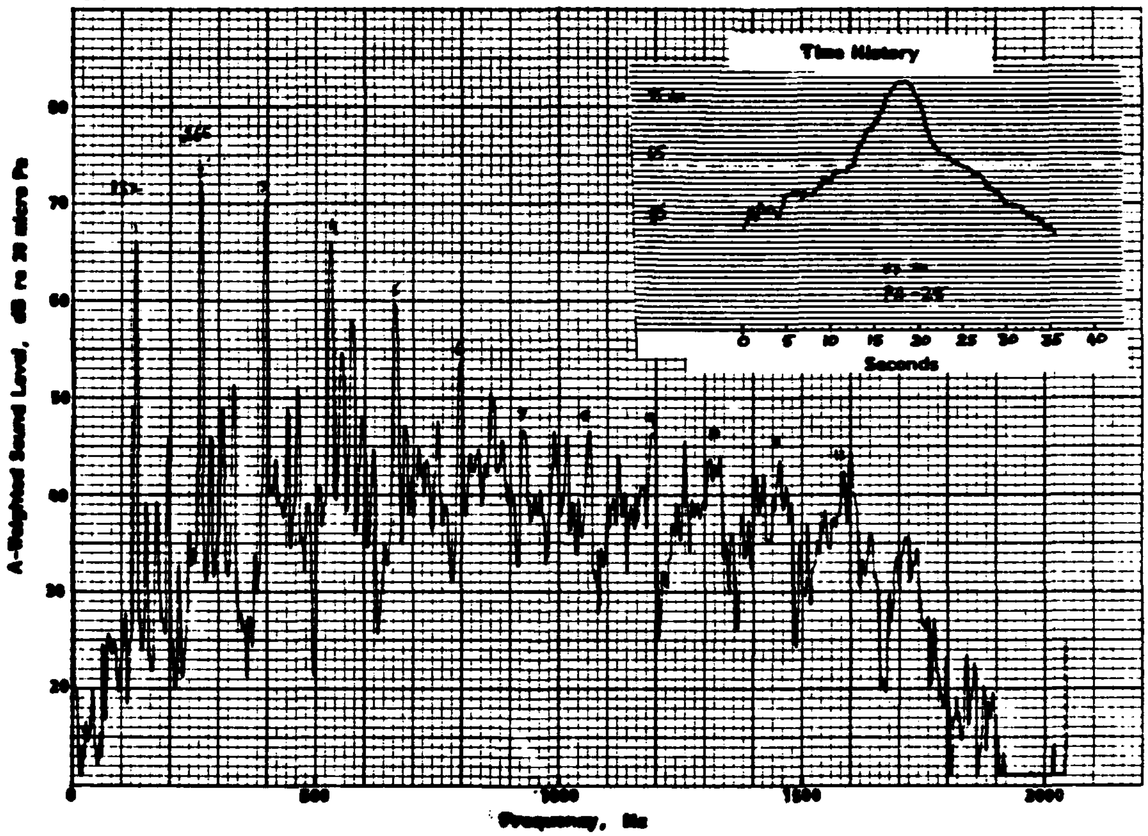
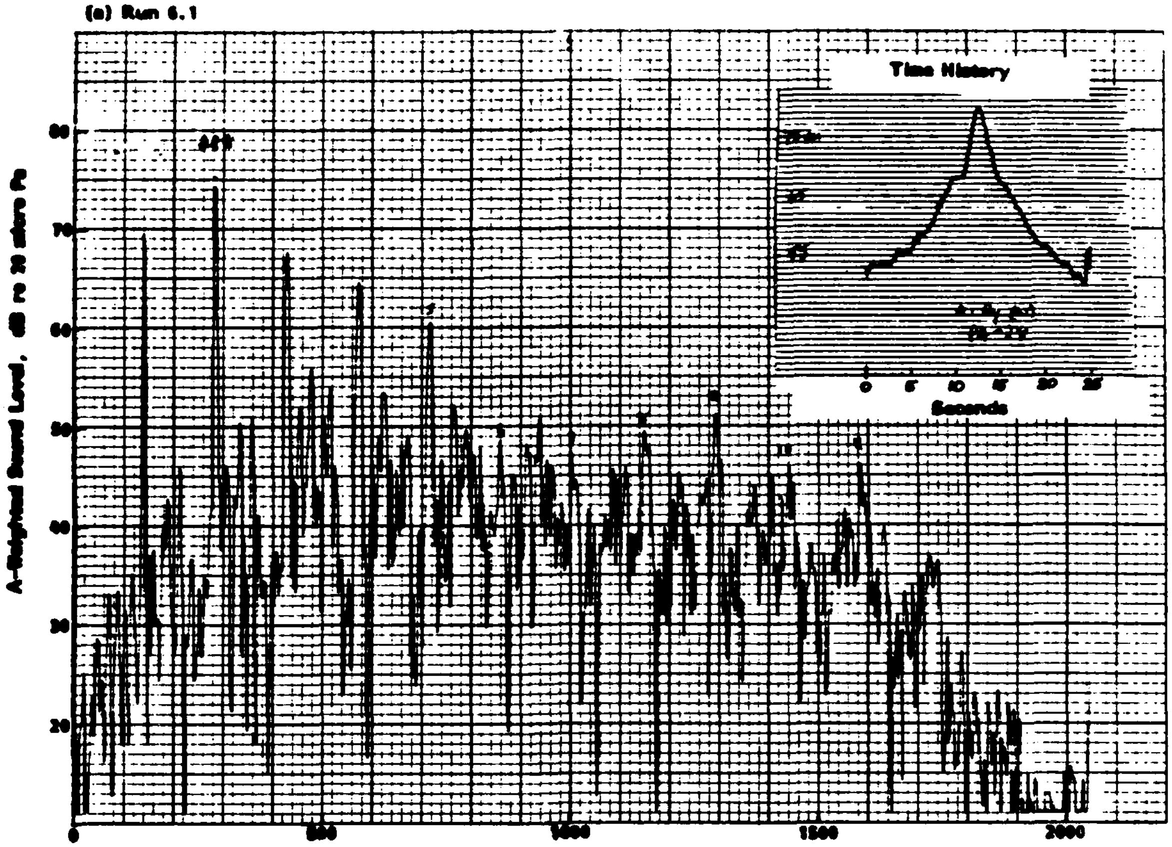


FIGURE B.11 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF PIPER PA-28RT-201T TURBO ARROW IV

(a) Run 6.1



(b) Run 6.4

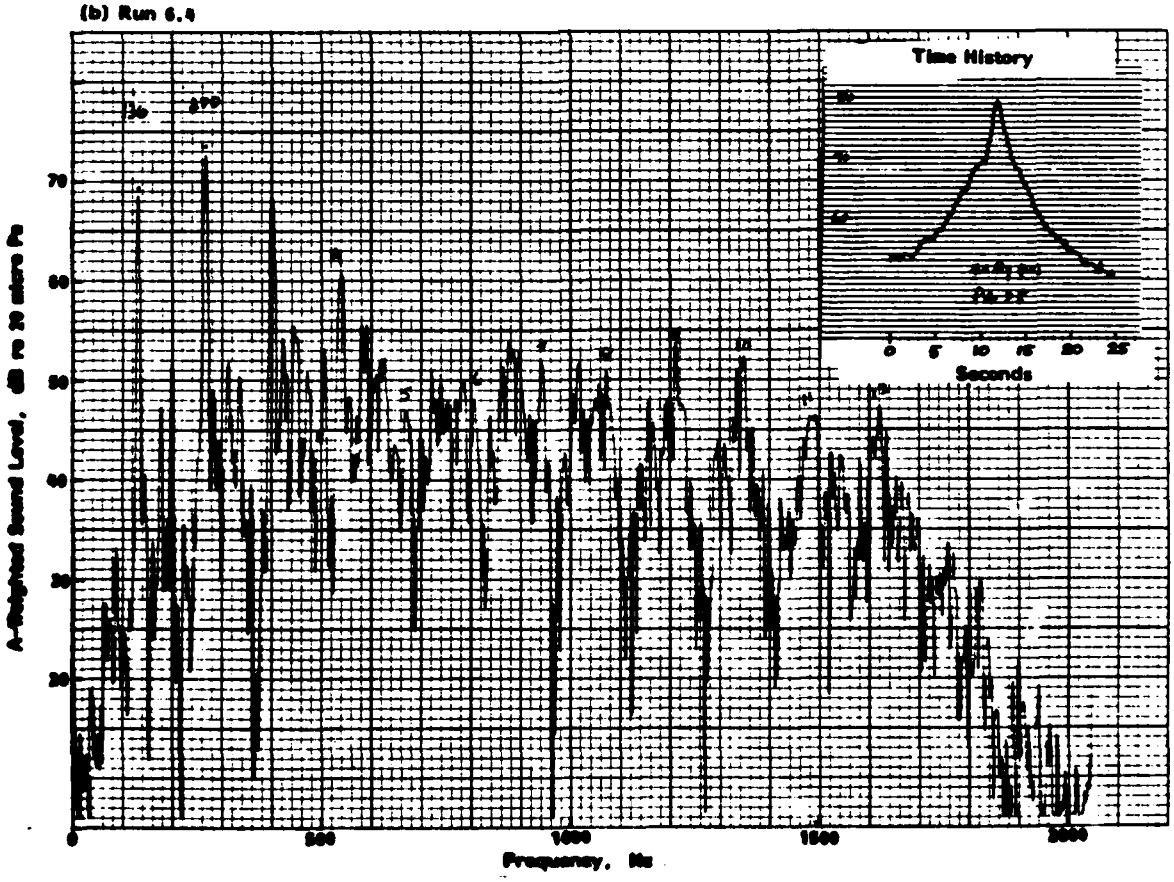


FIGURE B.12 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF PIPER PA-28RT-210T TURBO ARROW IV

(c) Run 6.5

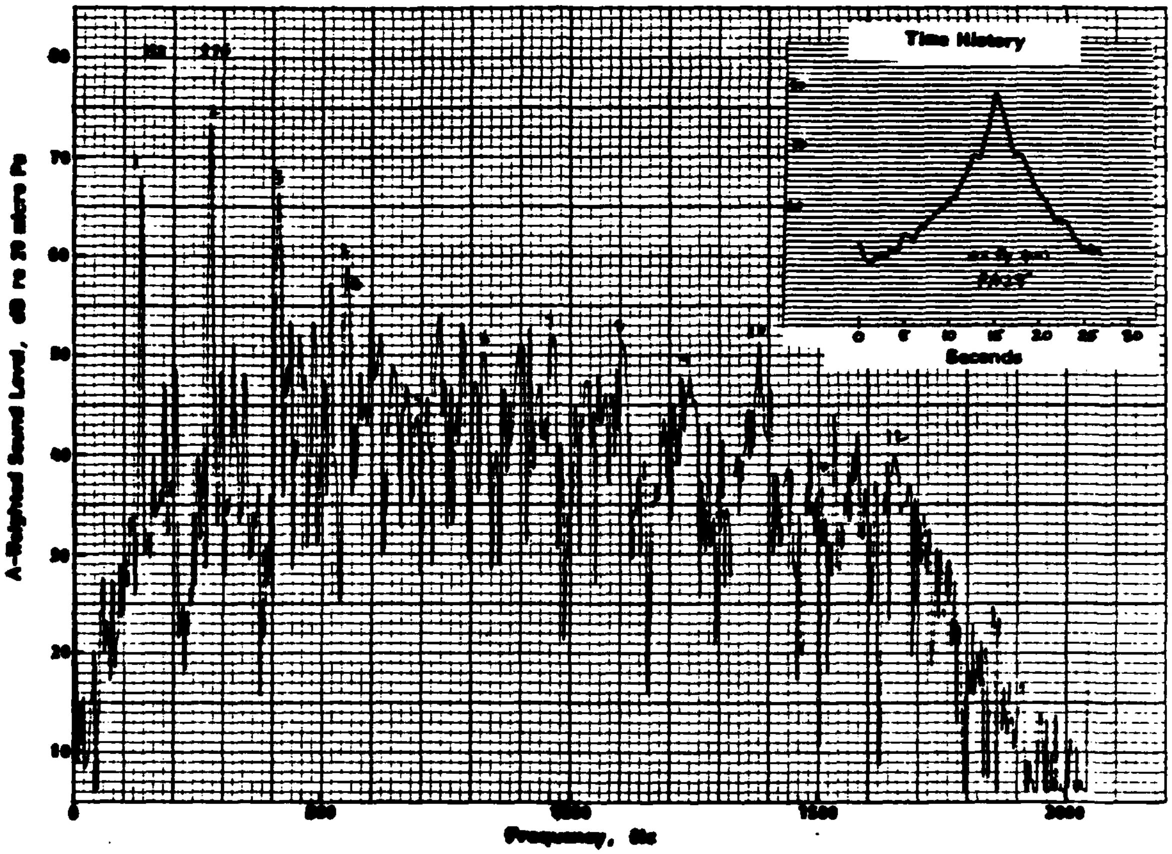
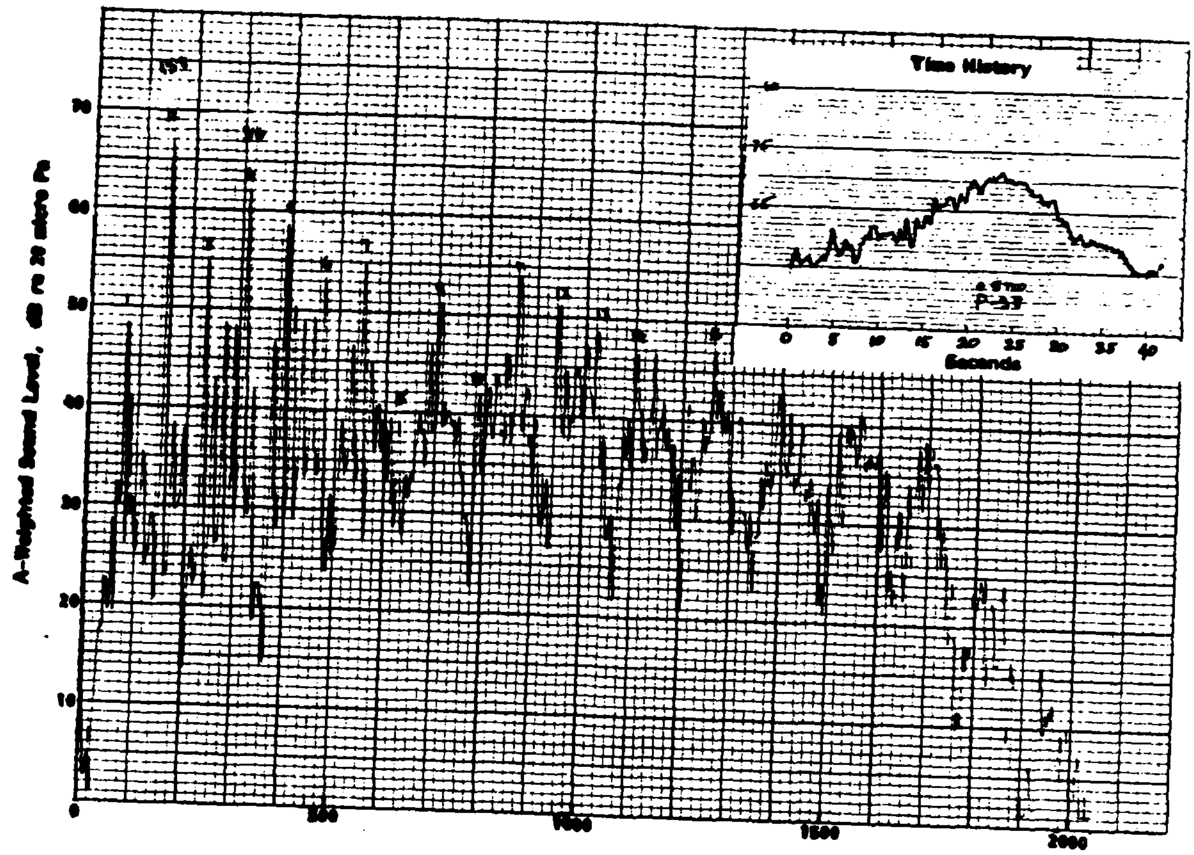


FIGURE B.12 CONTINUED

(a) Run 5



(b) Run 6

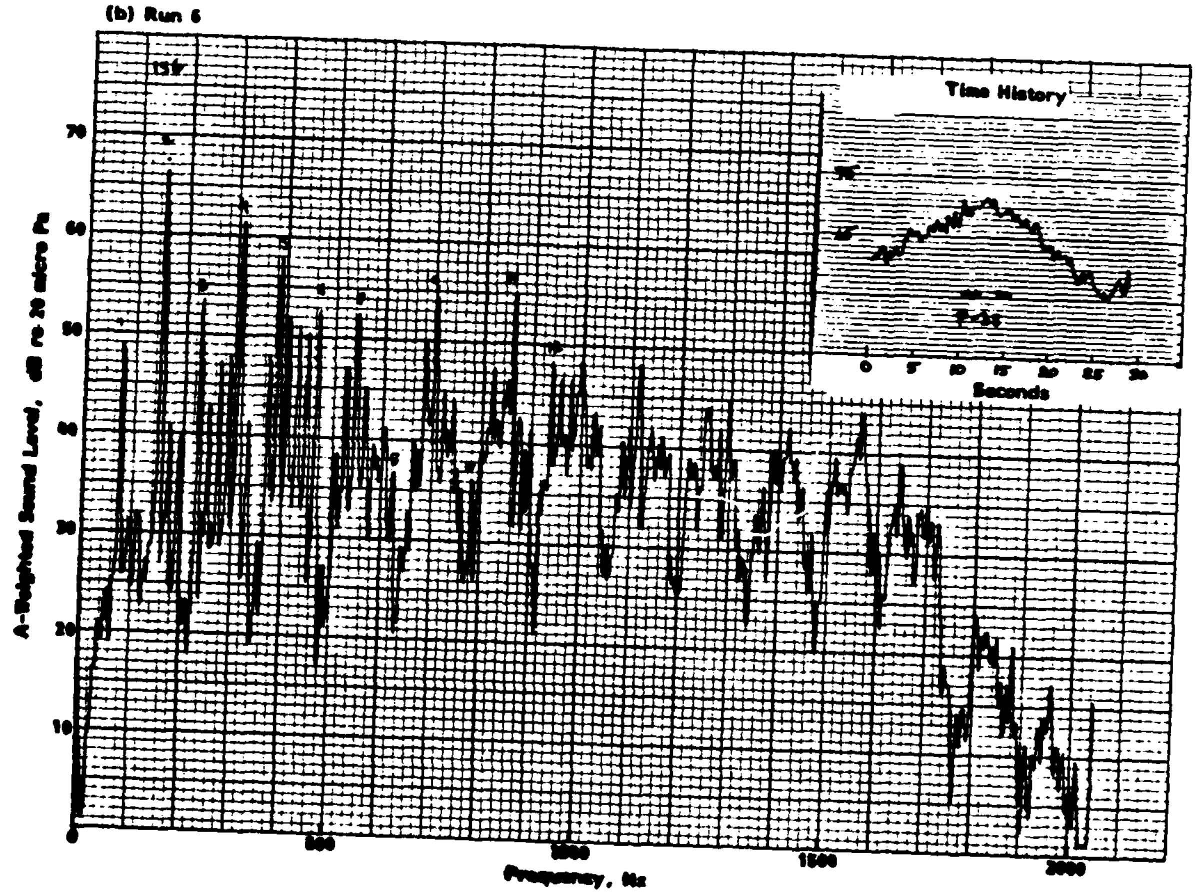
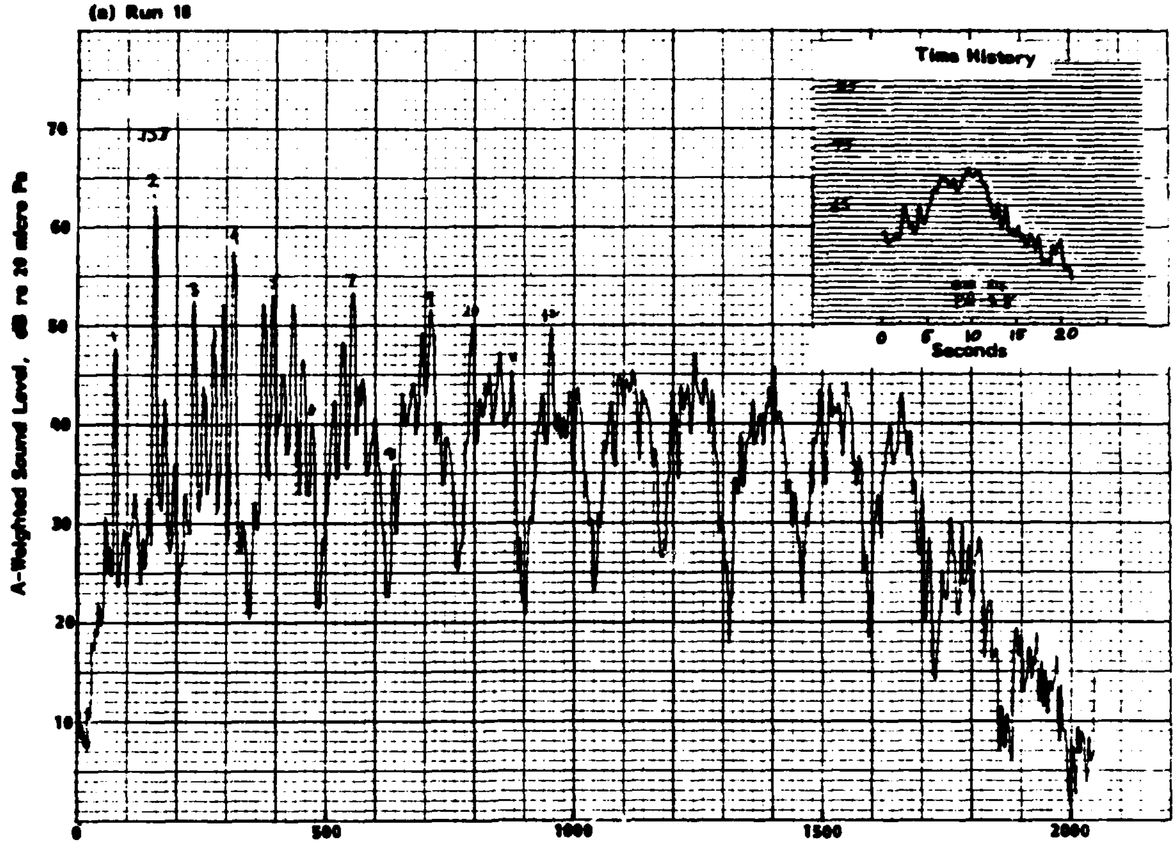


FIGURE B.13 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF PIPER PA-38-112 TOMAHAWK



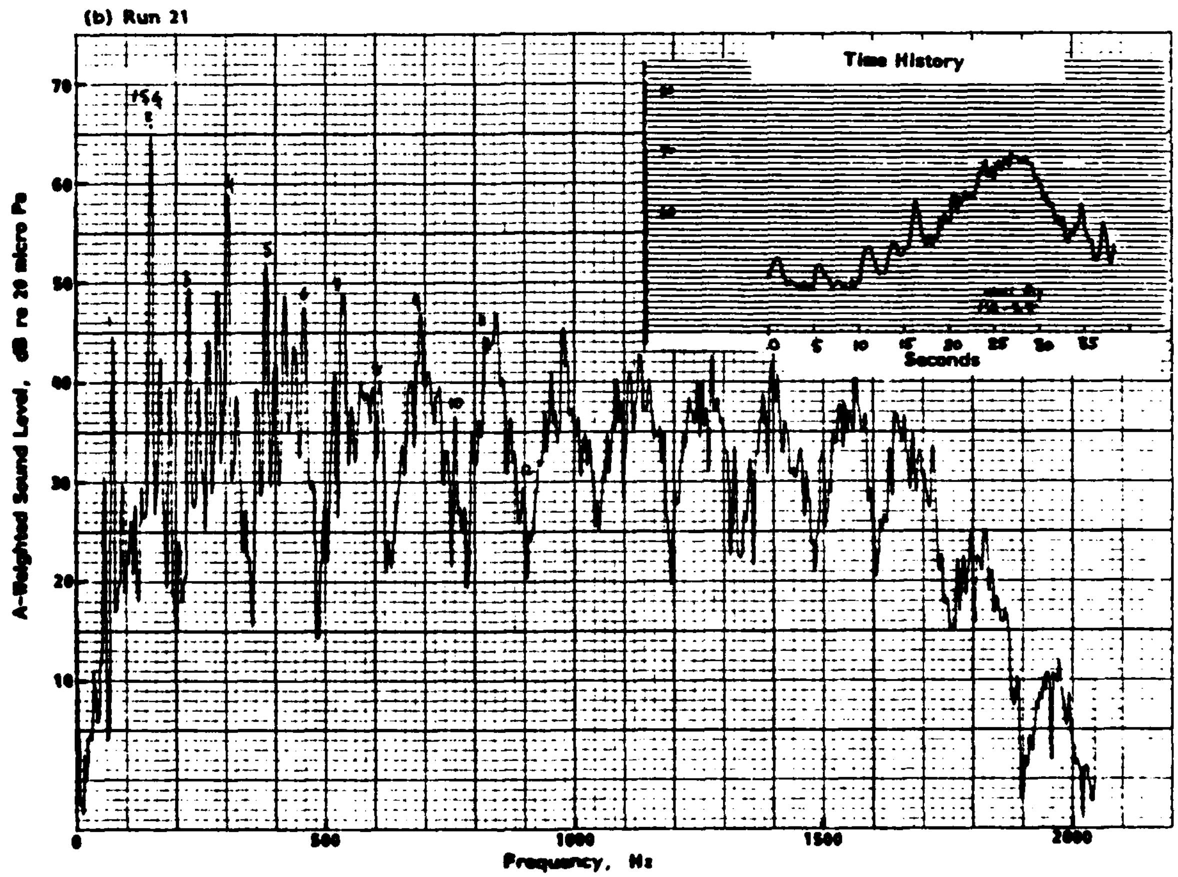
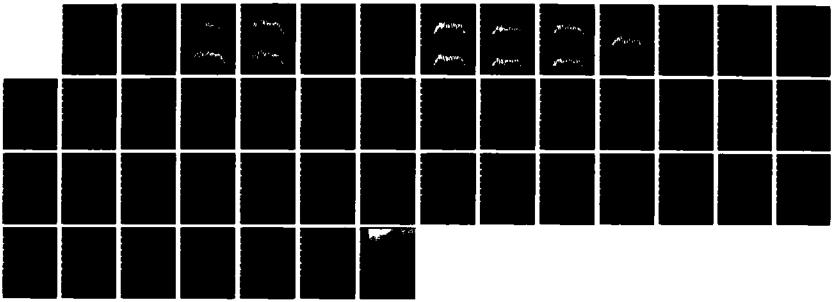
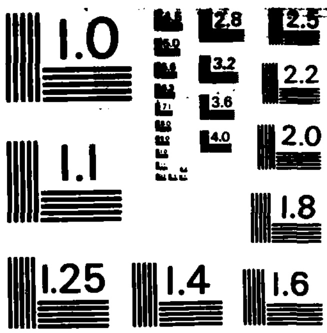


FIGURE B.14 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF PIPER PA-38-112 TOMAHAWK

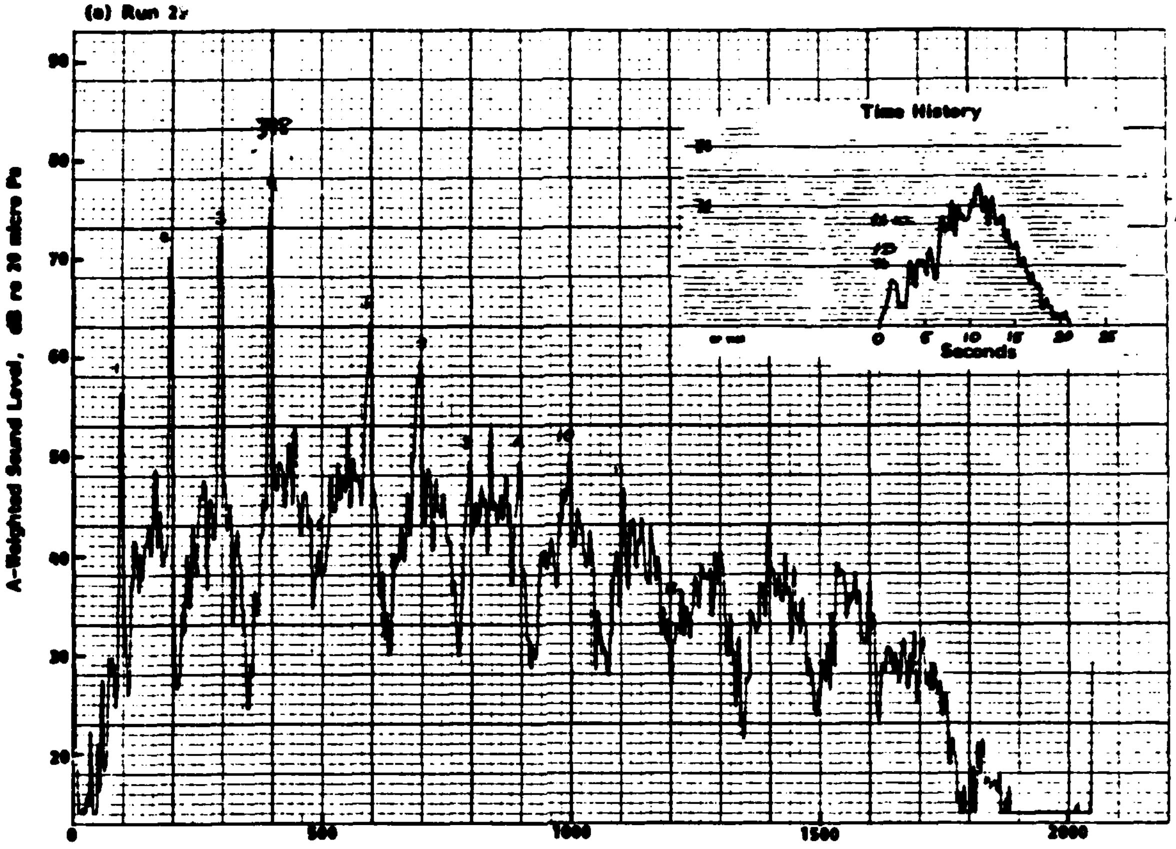
AD-A139 901 A COMPARISON OF MEASURED TAKE-OFF AND FLYOVER SOUND LEVELS FOR SEVERAL GE..(U) BOLT BERANEK AND NEWMAN INC CANOGA PARK CA J F WILBY ET AL. FEB 84 BBN-5450 2/2

UNCLASSIFIED FAA/EE-84-9 DTFA01-83-P-81230 F/G 20/1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



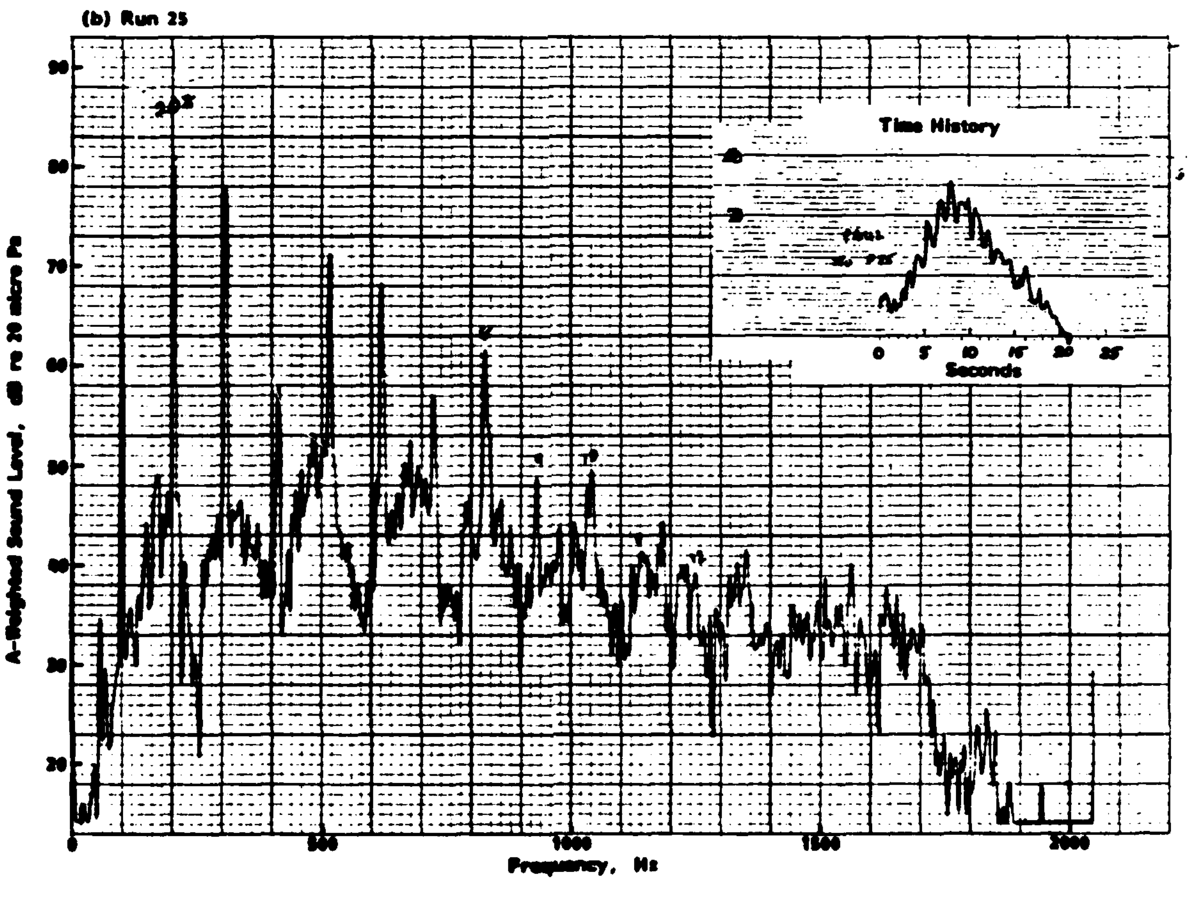
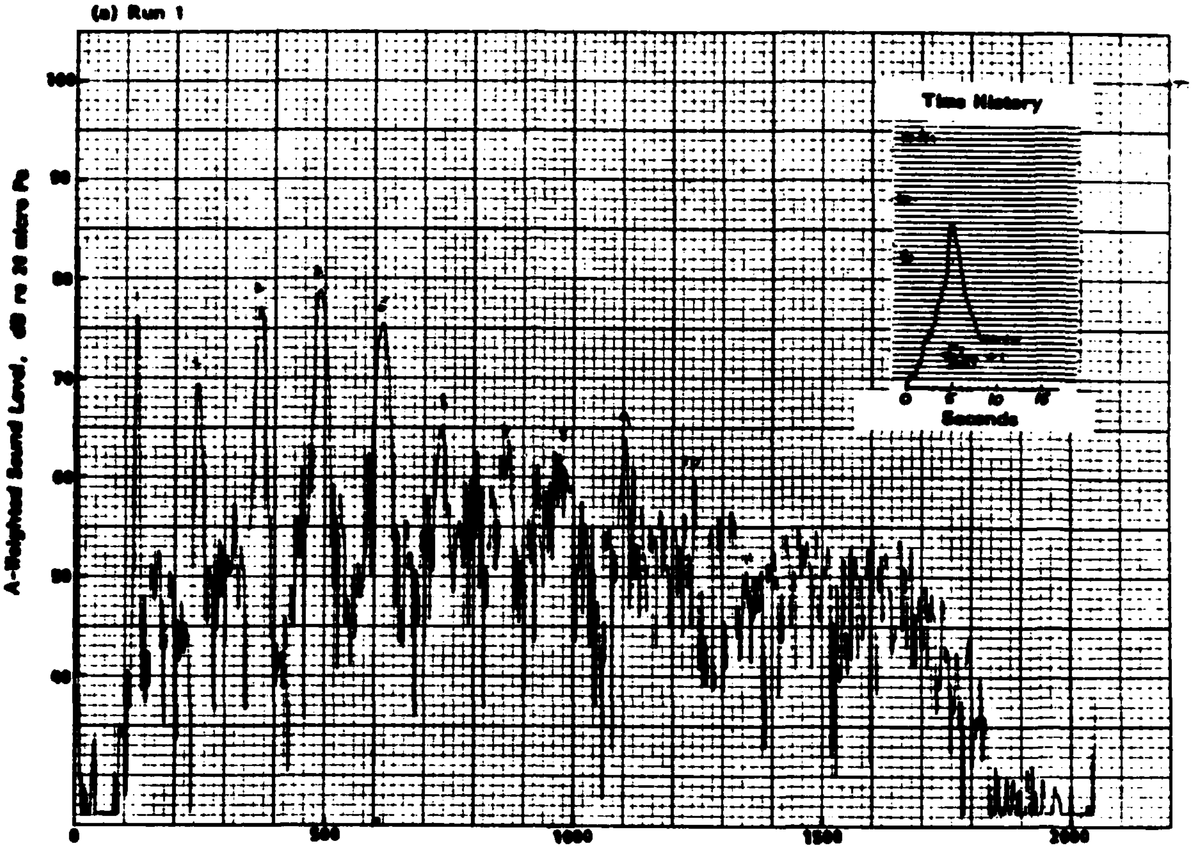


FIGURE B.15 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR TAKE-OFF OF PIPER PA-42 CHEYENNE



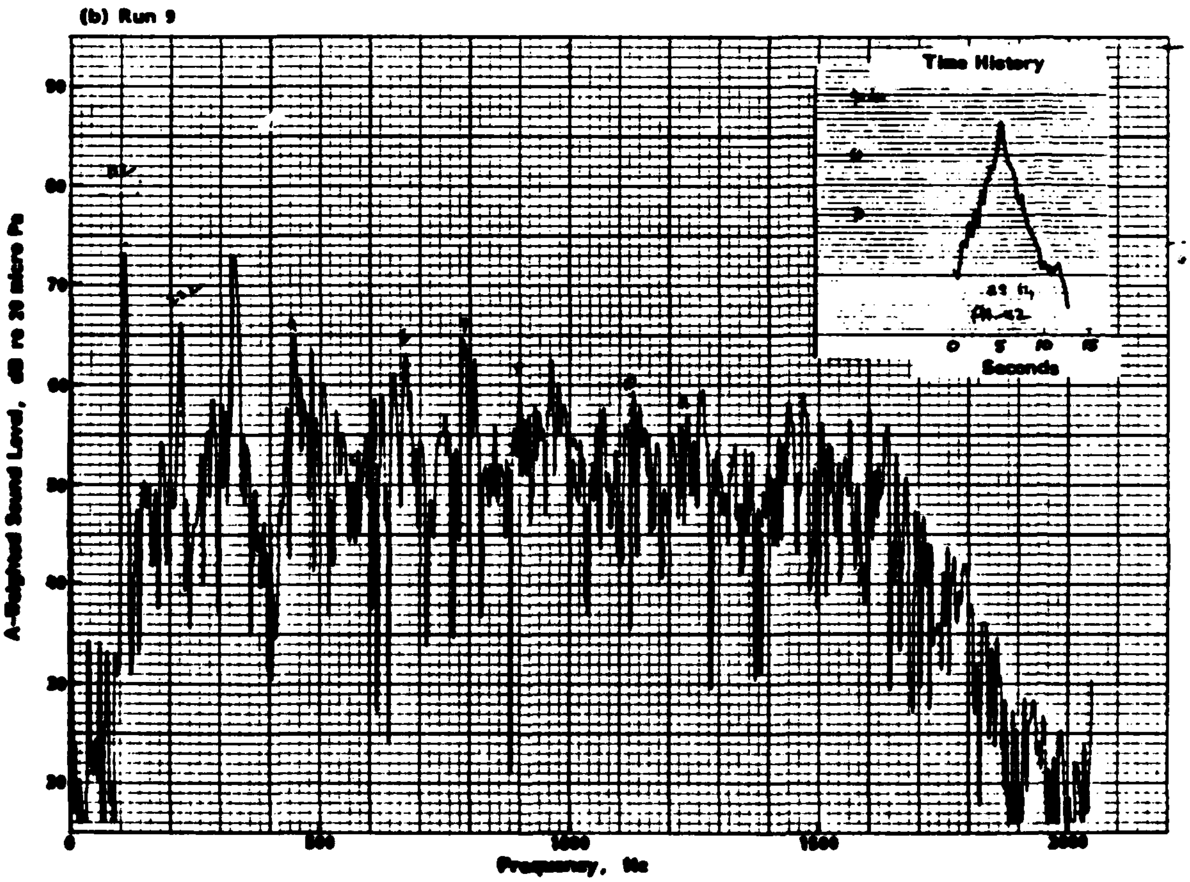
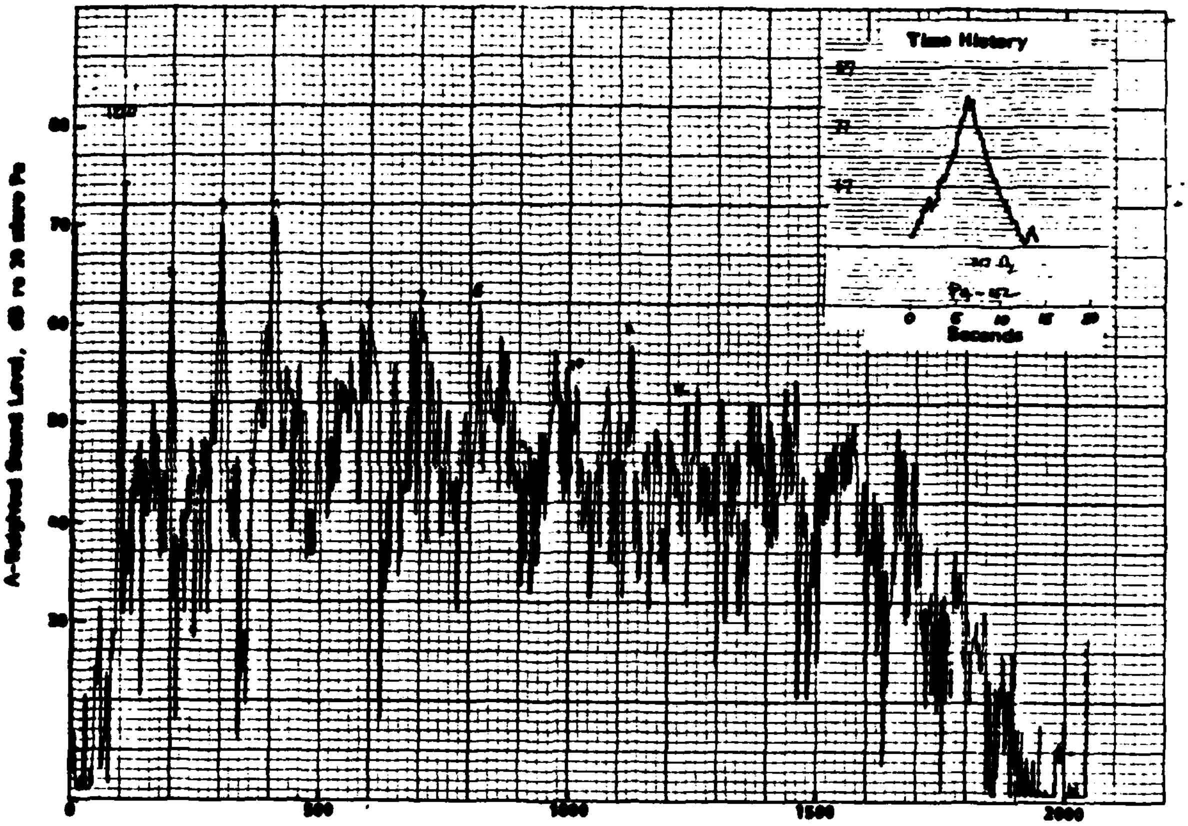


FIGURE B.16 A-WEIGHTED SOUND LEVEL TIME HISTORIES AND NARROWBAND SPECTRA FOR FLYOVER OF PIPER PA-42 CHEYENNE

(c) Run 17



(d) Run 20

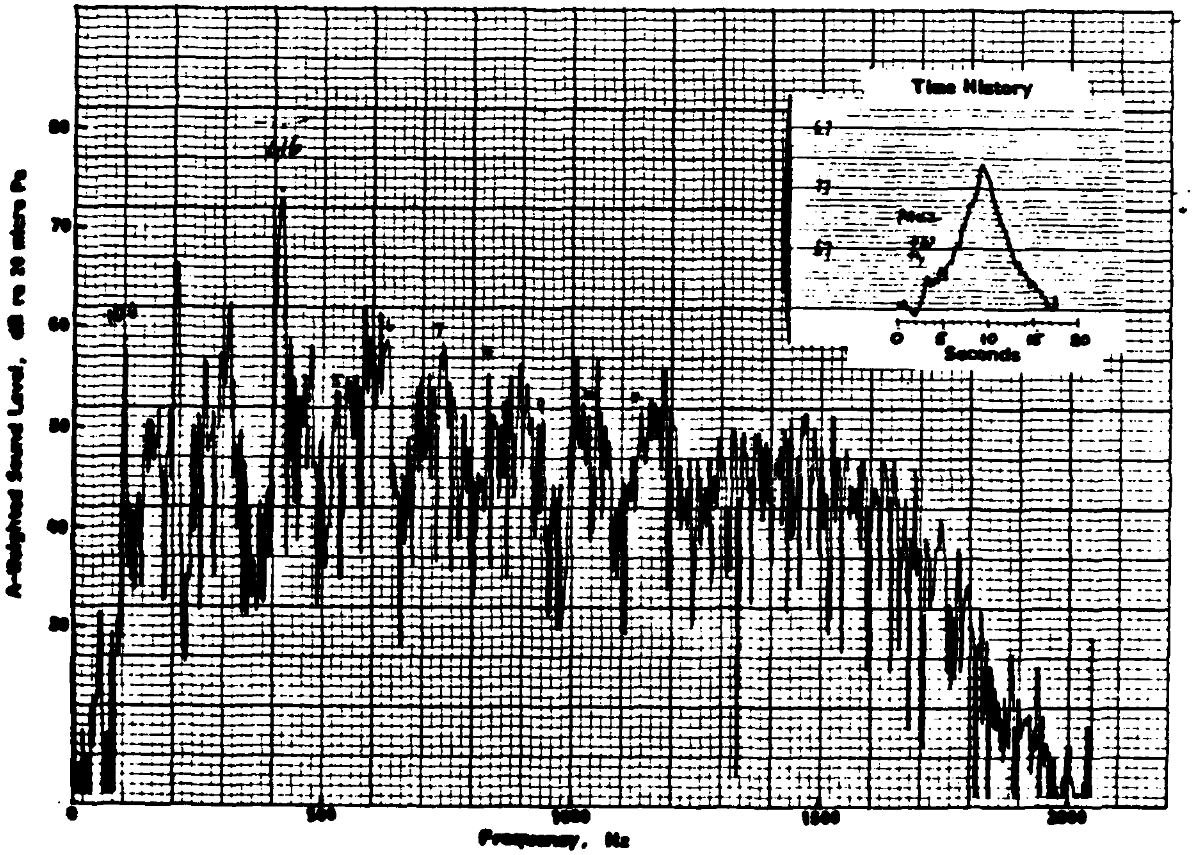


FIGURE B.16 CONTINUED

APPENDIX C

A-WEIGHTED NARROWBAND SOUND LEVEL SPECTRA MEASURED WITH GROUND-LEVEL MICROPHONE FOR CESSNA 210 CENTURION

APPENDIX C

A-WEIGHTED NARROWBAND SOUND LEVEL SPECTRA MEASURED WITH GROUND-LEVEL MICROPHONE FOR CESSNA 210 CENTURION

In addition to the narrowband spectra presented in Appendix B, narrowband data reduction was performed also for measurements made by the ground-plane microphone during take-offs and fly-overs of the Cessna 210. The resulting A-weighted narrowband sound level spectra are contained in Figures C.1 and C.2. Corresponding spectra measured by the microphone located 4 feet above the ground surface are shown in Figures B.5 and B.6, respectively.

The data reduction procedure used for the ground plane microphone recording was the same as that described in Appendix B.

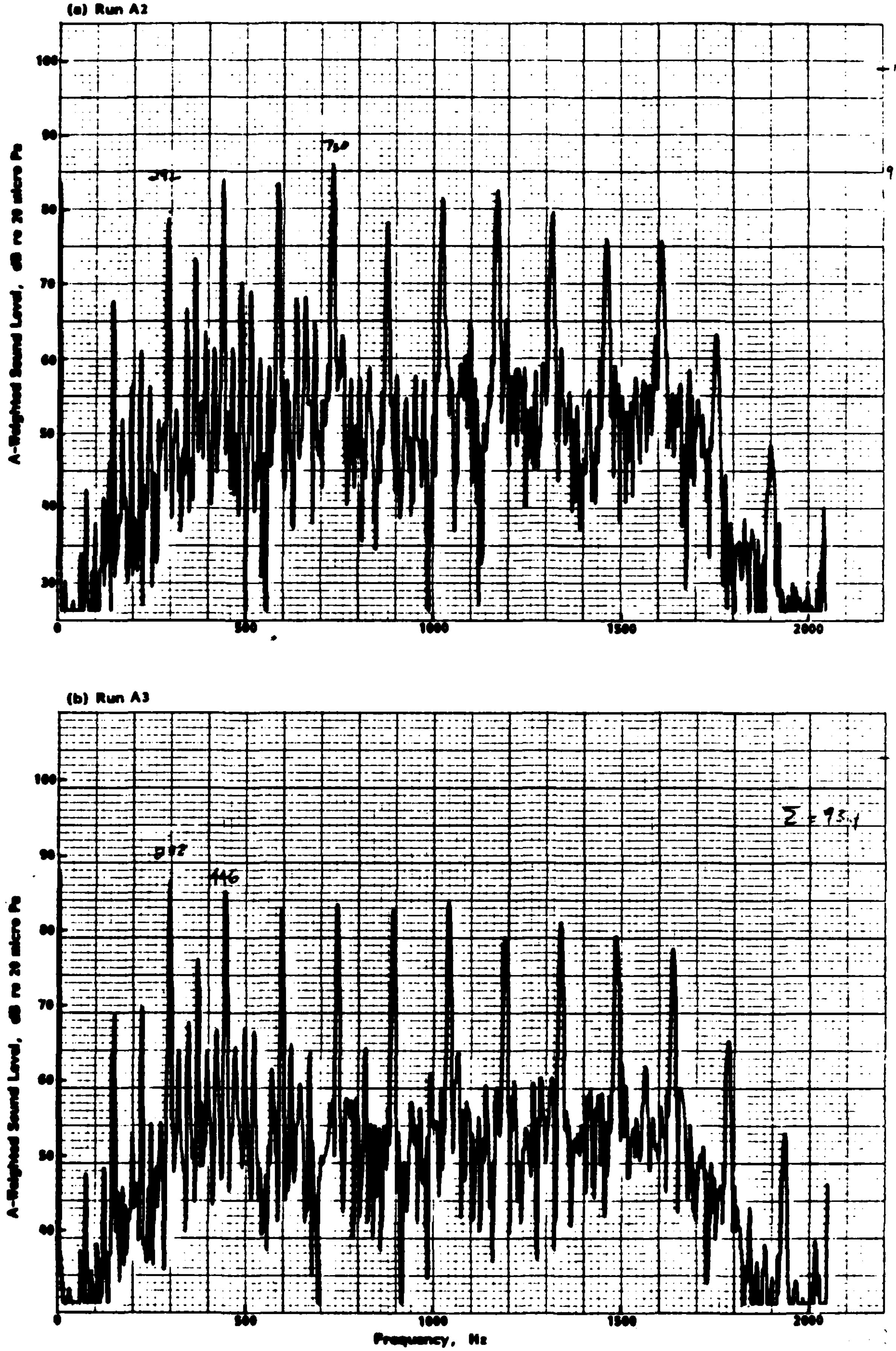
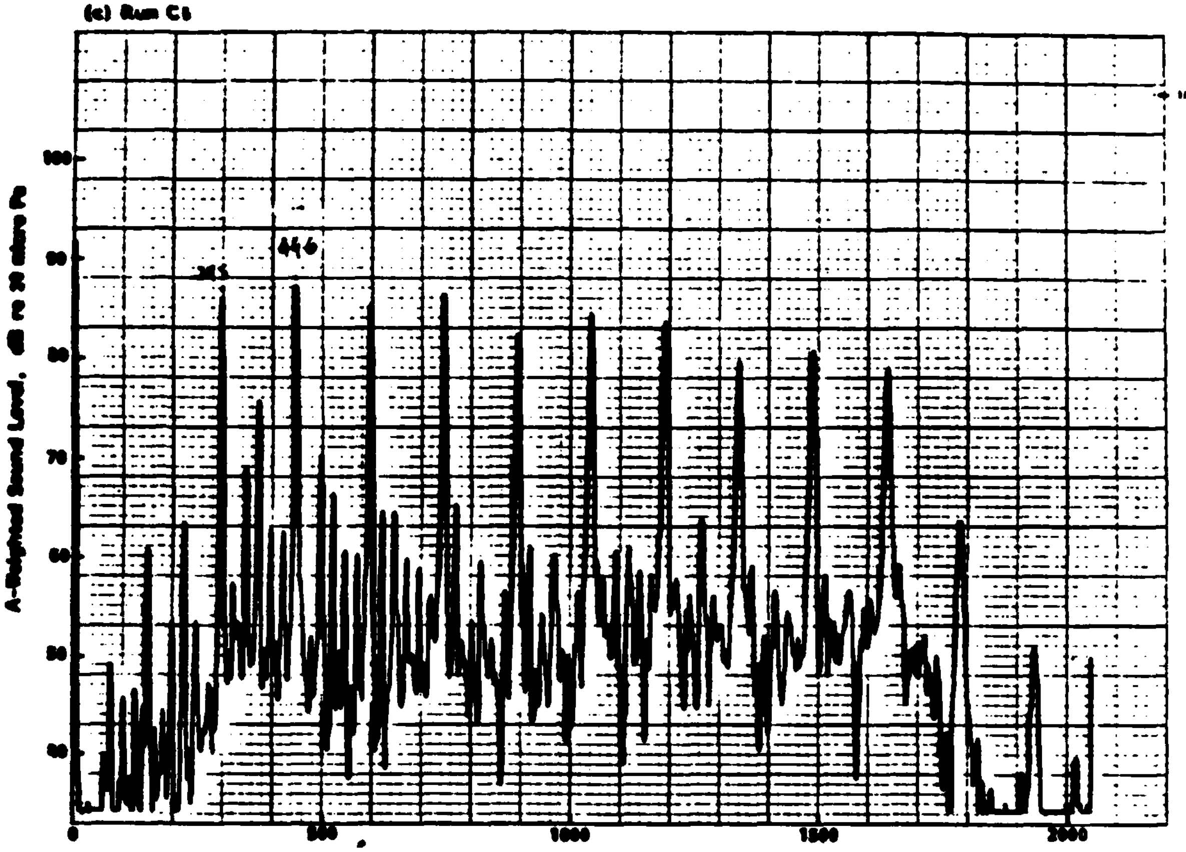


FIGURE C.1 A-WEIGHTED NARROWBAND SPECTRA FOR TAKE-OFF OF CESSNA 210 CENTURION; GROUND-PLANE MICROPHONE



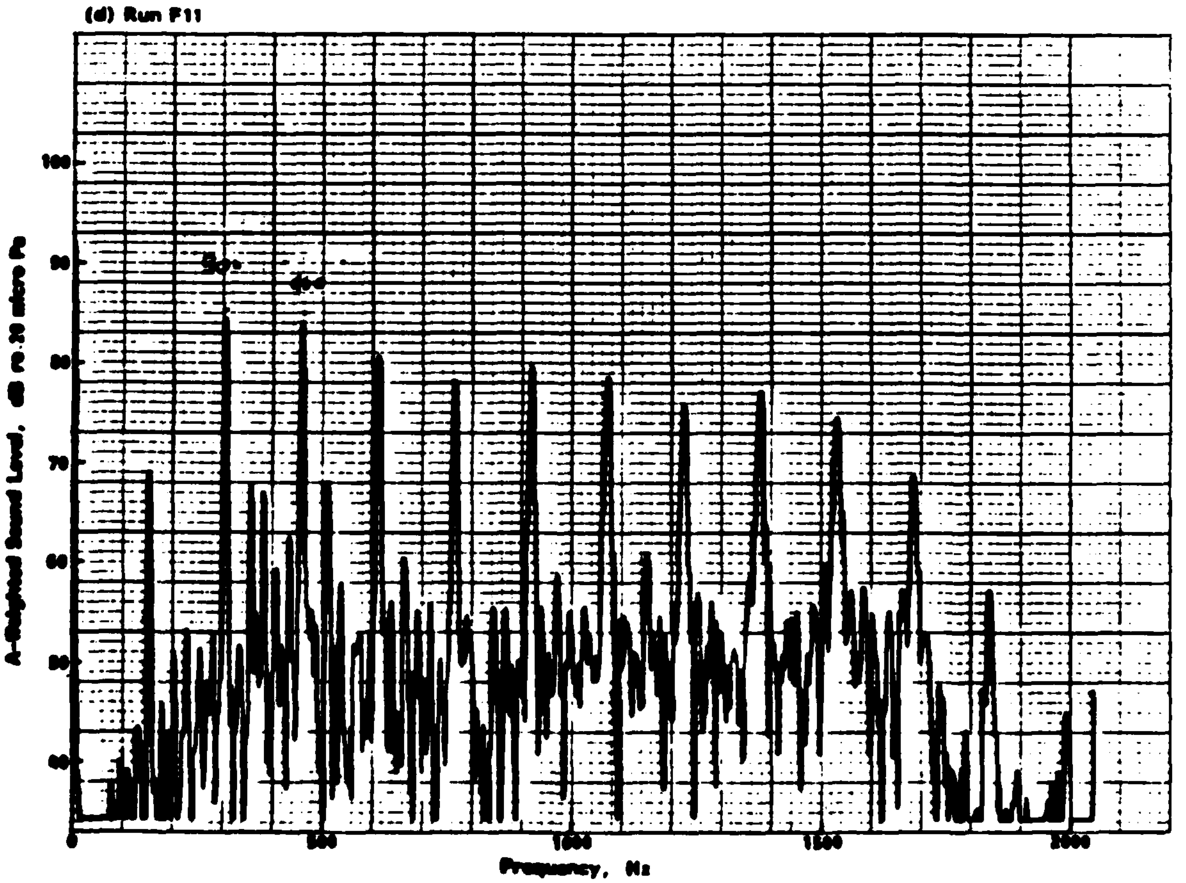
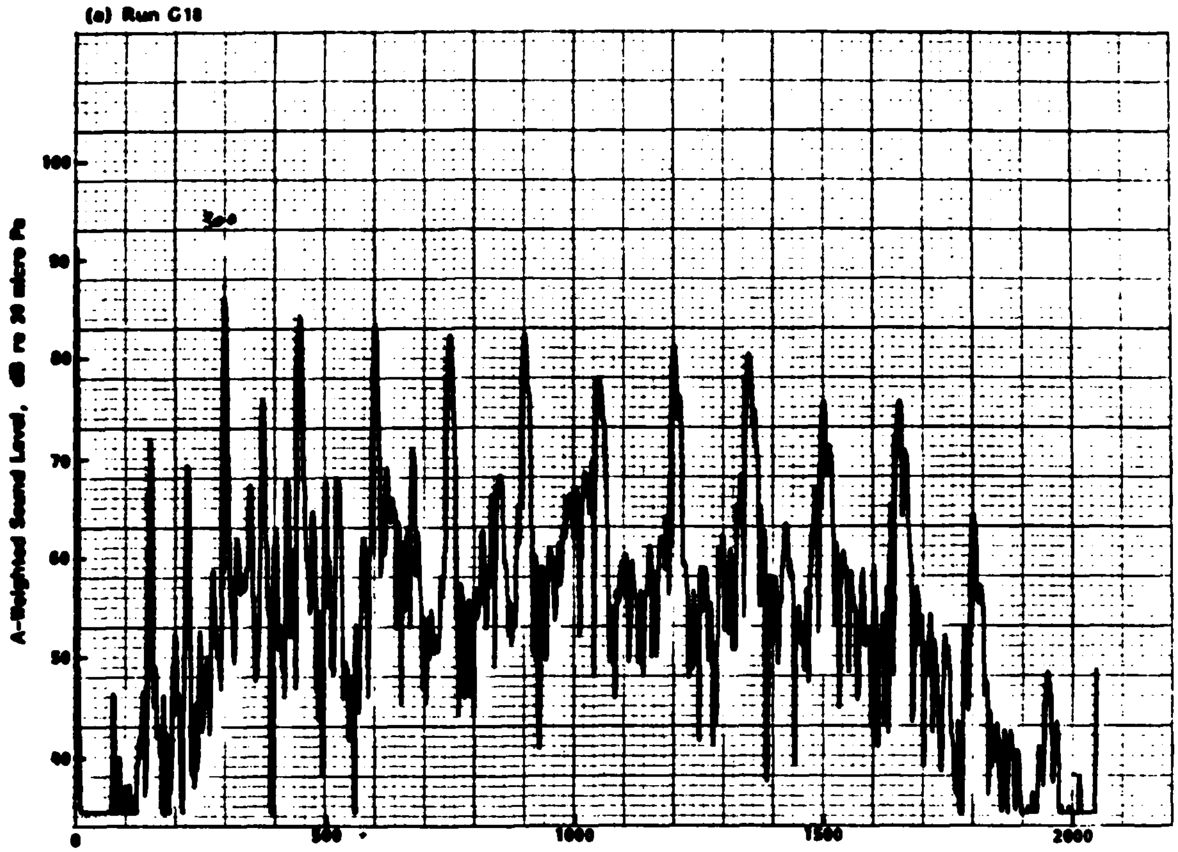


FIGURE C.1 CONTINUED



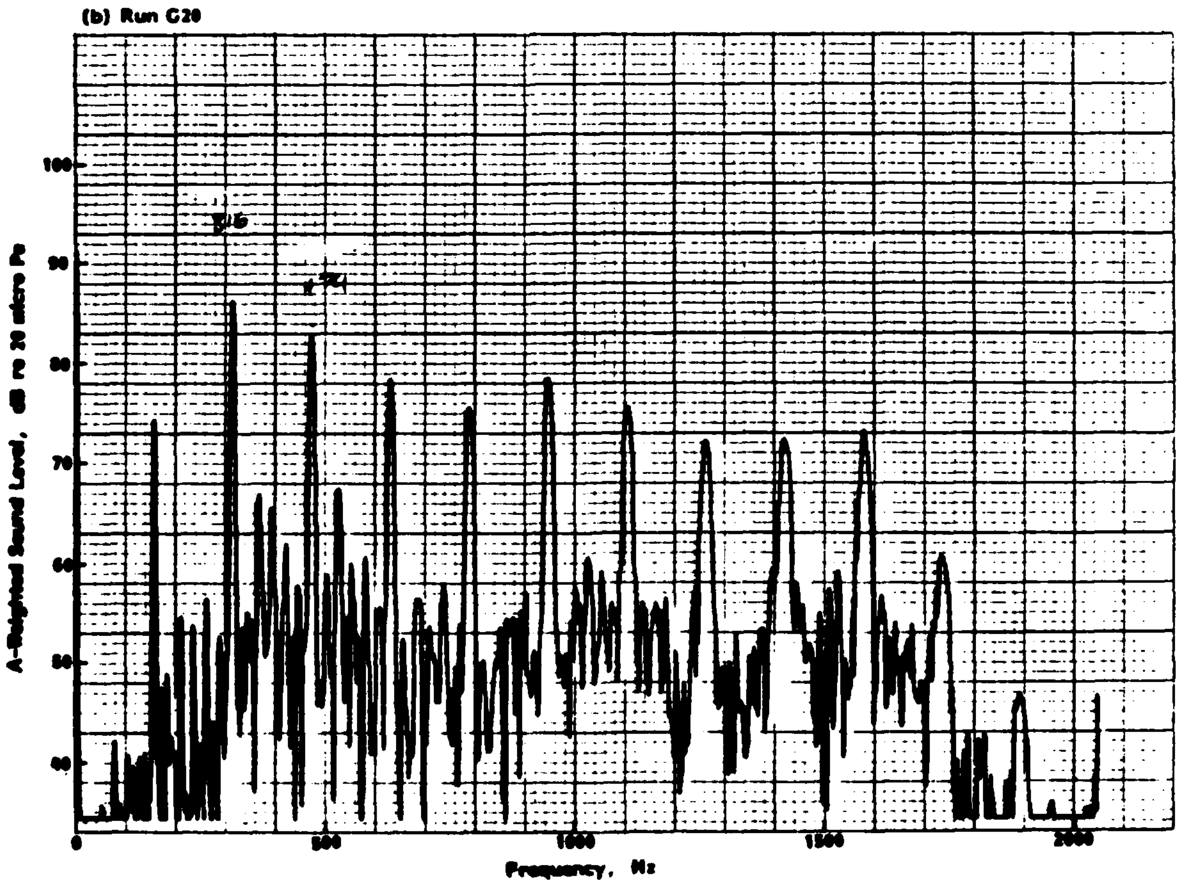


FIGURE C.2 A-WEIGHTED NARROWBAND SPECTRA FOR FLYOVER OF CESSNA 210 CENTURION; GROUND-PLANE MICROPHONE

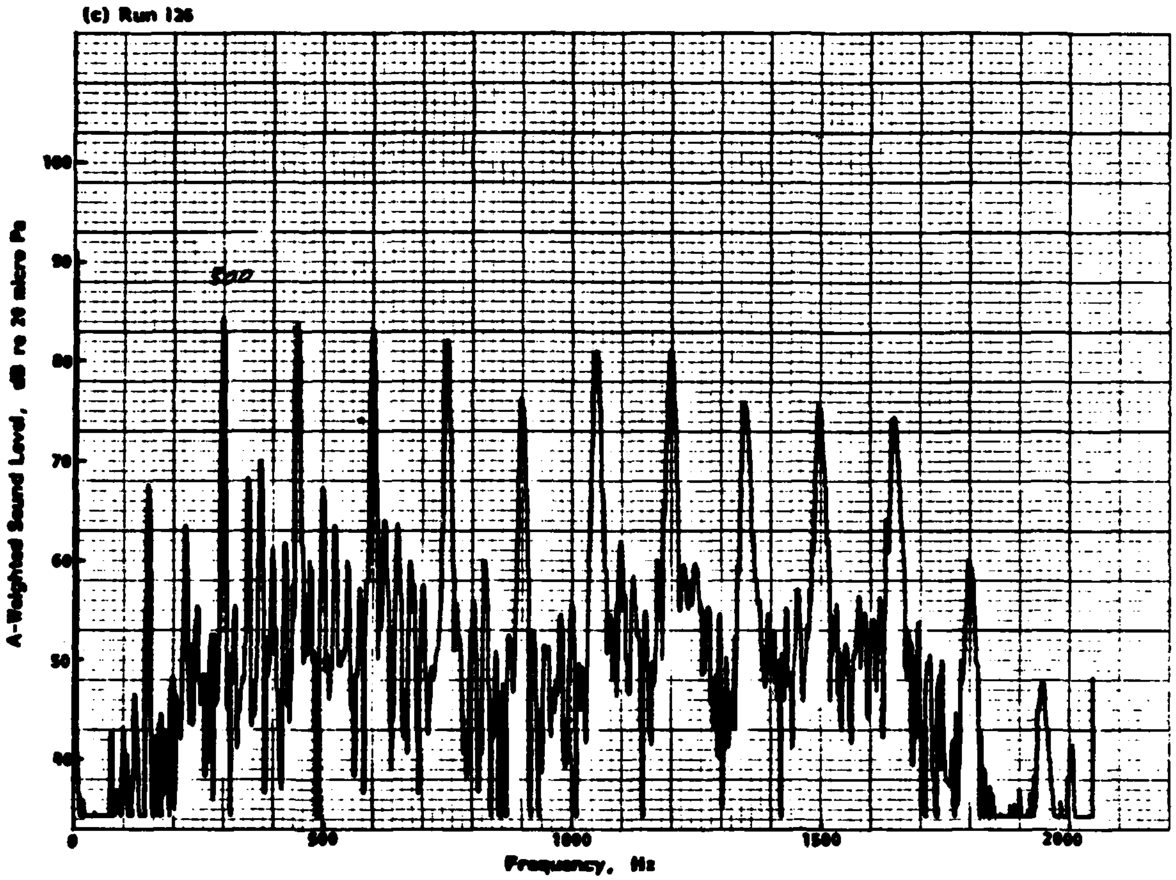


FIGURE C.2 CONTINUED

APPENDIX D
A-WEIGHTED SOUND LEVELS AT HARMONICS OF BLADE PASSAGE FREQUENCY

APPENDIX D

A-WEIGHTED SOUND LEVELS AT HARMONICS OF BLADE PASSAGE FREQUENCY

The narrowband sound level spectra in Appendices B and C contain families of discrete frequency components at the fundamental and higher-order harmonics of the propeller blade passage frequency. (In this report the terms "fundamental" and "first-order harmonic" are taken to be synonymous.) It is difficult, however, to compare harmonic sound levels for different flight conditions. Thus, the A-weighted sound levels associated with the propeller blade passage harmonics have been replotted in Figures D.1 through D.9 for each airplane and, in the case of the Cessna 210 Centurion, for the two microphone heights (Figures D.3 and D.4).

The curves in the figures distinguish between takeoff and flyover sound levels. In addition, sound levels associated with flyover conditions at takeoff (maximum) rpm are identified separately from other flyover data.

The sound levels shown in Figures D.1 through D.9 have been normalized to an aircraft altitude of 500 feet using the inverse square law associated with spherical spreading. It is realized that other scaling laws are used for A-weighted sound levels of propeller-driven aircraft; for example, FAA normalizes sound levels according to distance to the power 2.2. However, when considering sound levels at discrete frequencies it is more appropriate to use the inverse square law. In any case, the corrections are small for most data points.

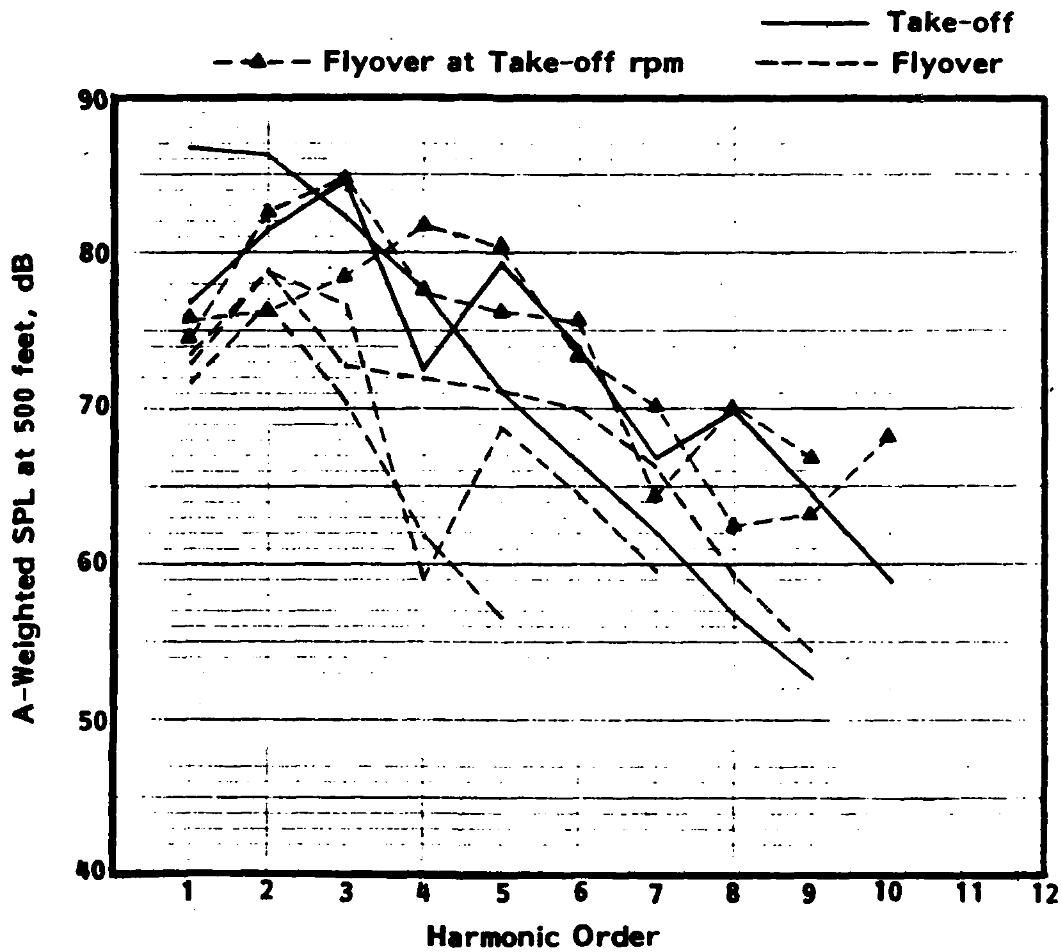


FIGURE D.1 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR BEECH B58P BARON

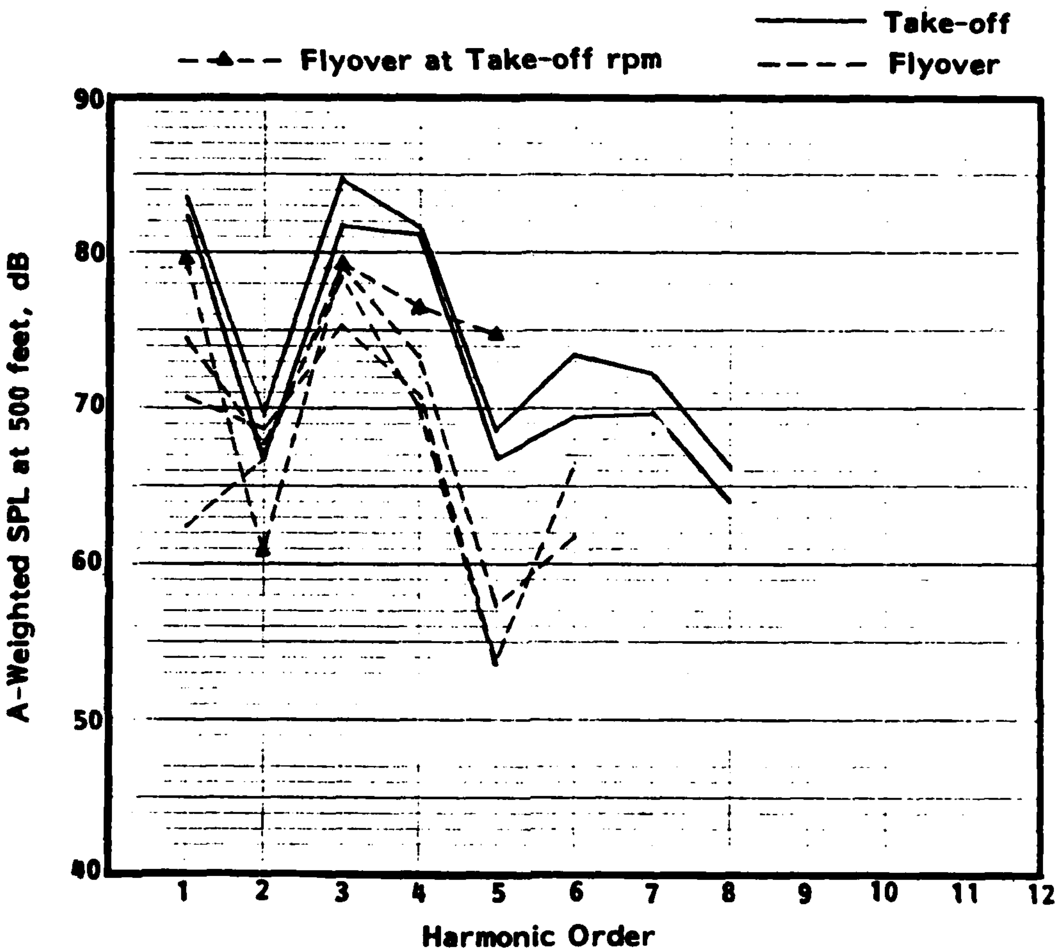


FIGURE D.2 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR BEECH B200 SUPER KING AIR

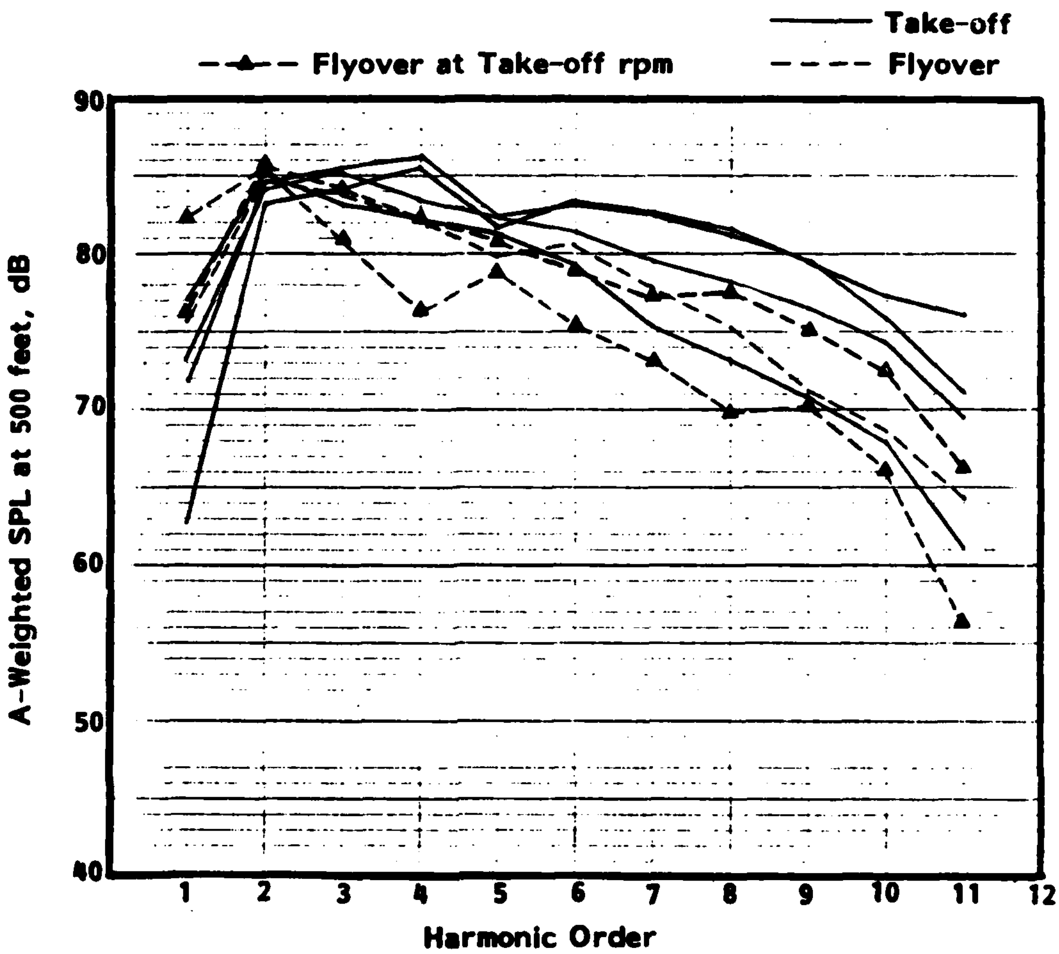


FIGURE D.3 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR CESSNA 210 CENTURION

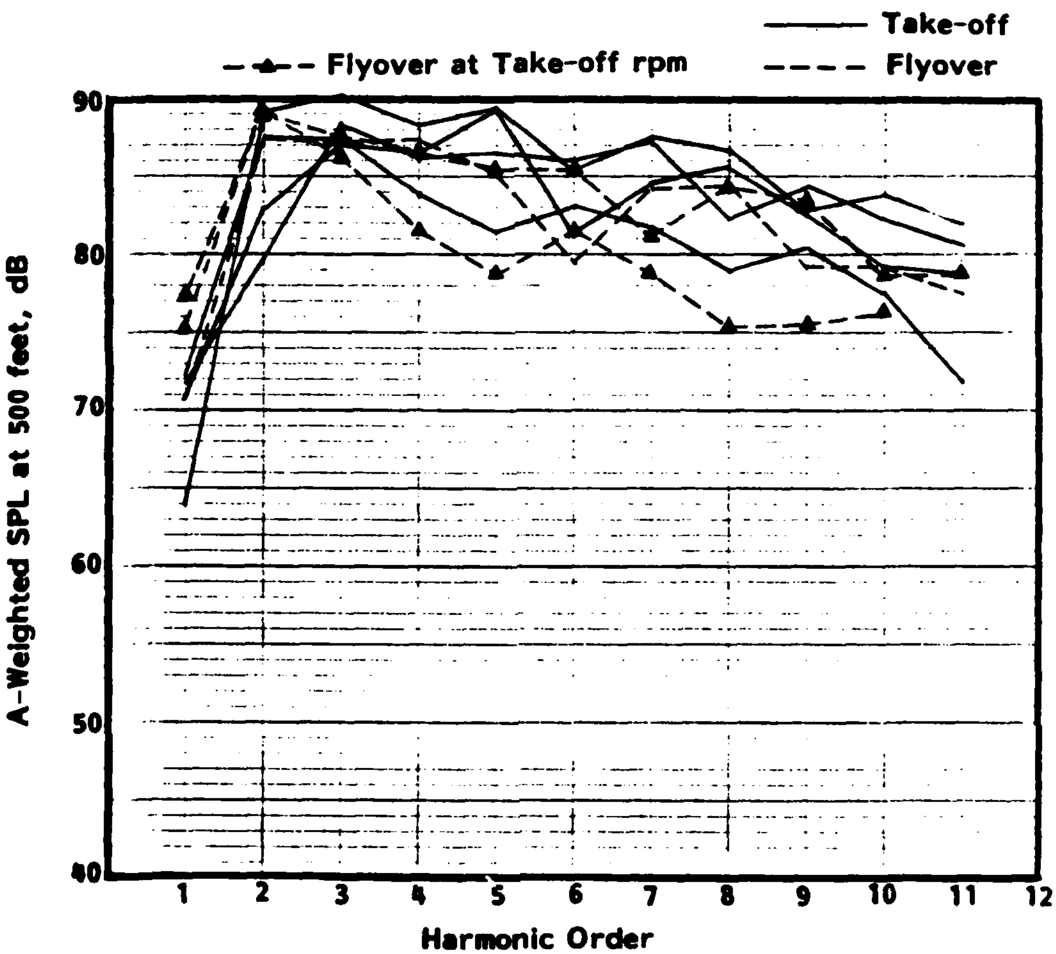


FIGURE D.4 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR CESSNA 210 CENTURION (GROUND-PLANE MICROPHONE)

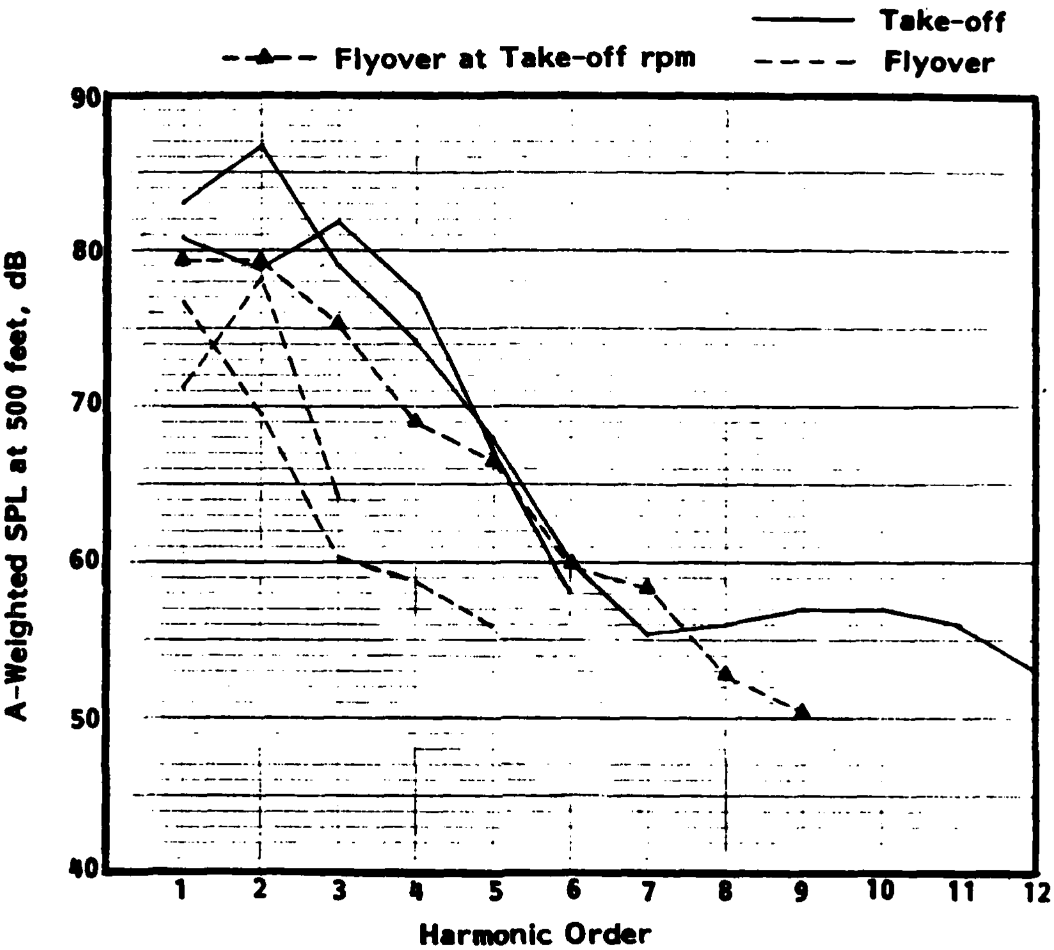


FIGURE D.5 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR CESSNA 414 CHANCELLOR

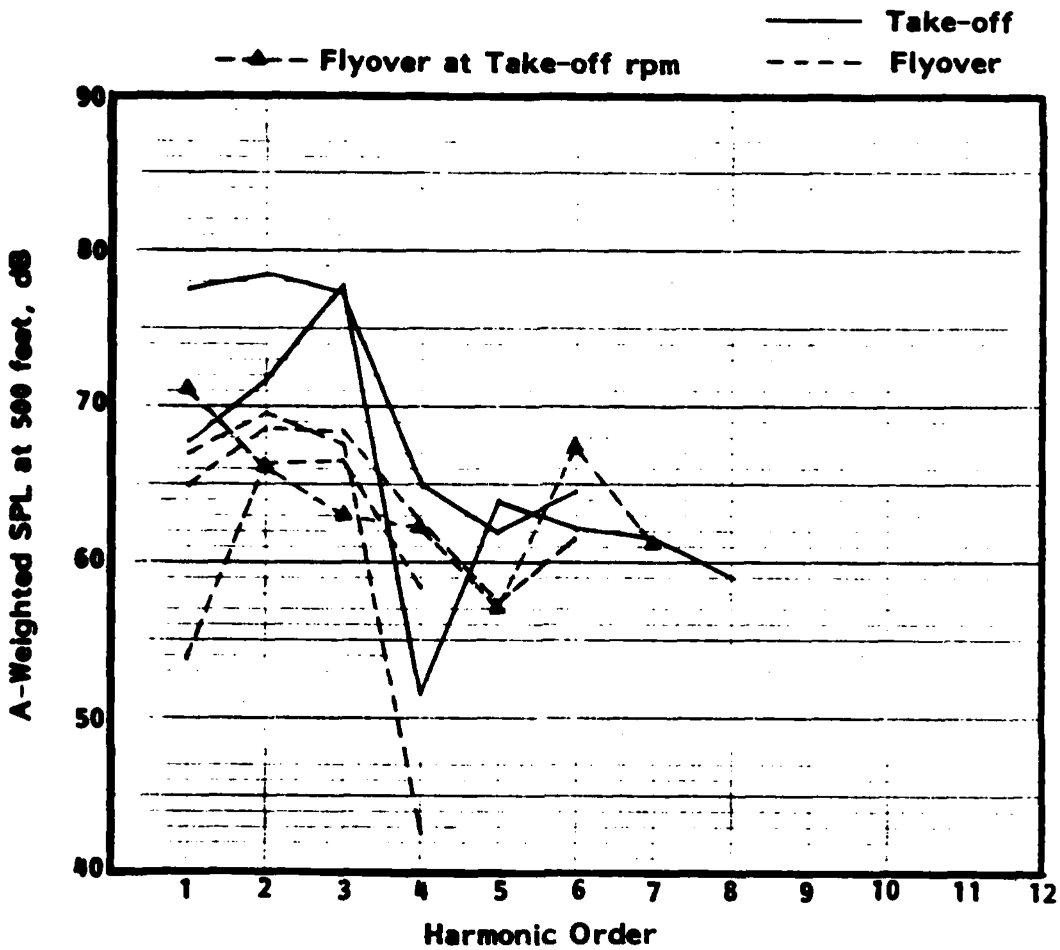


FIGURE D.6 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR CESSNA 425 CONQUEST 1

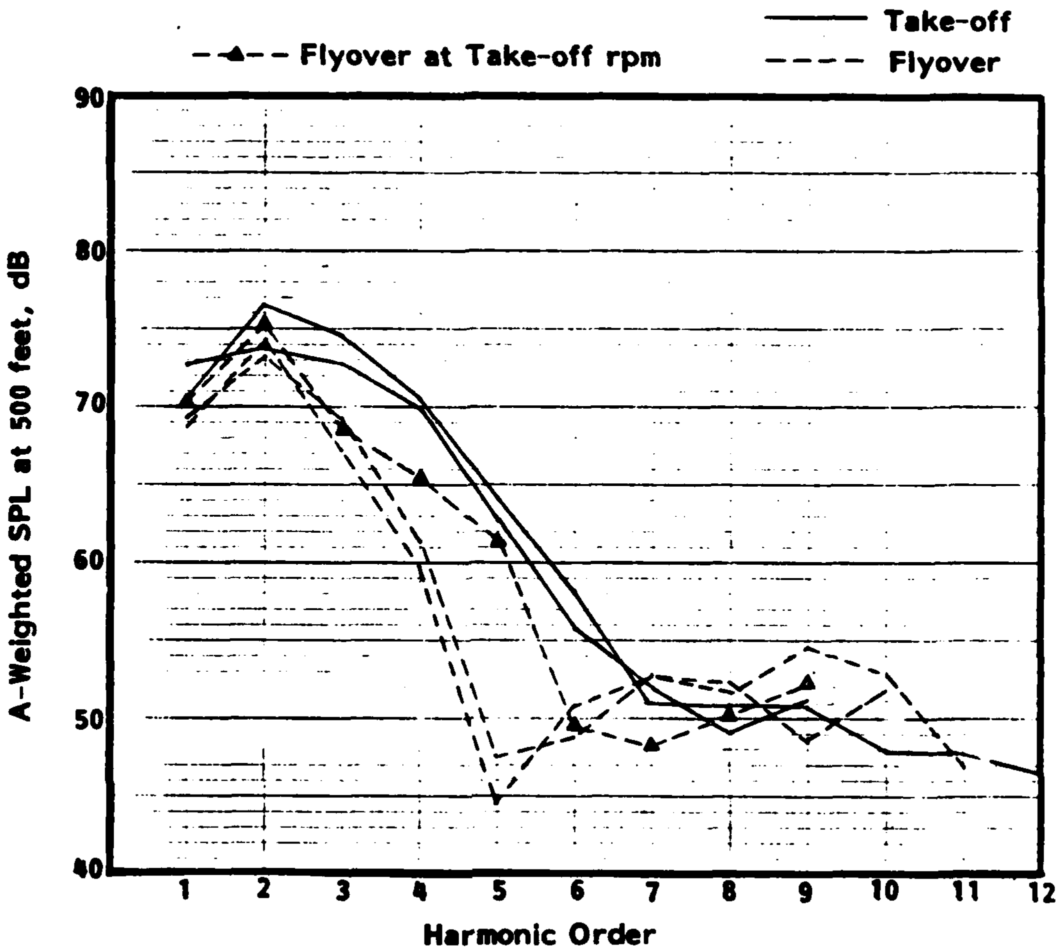


FIGURE D.7 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR PIPER PA-28RT-201T TURBO ARROW

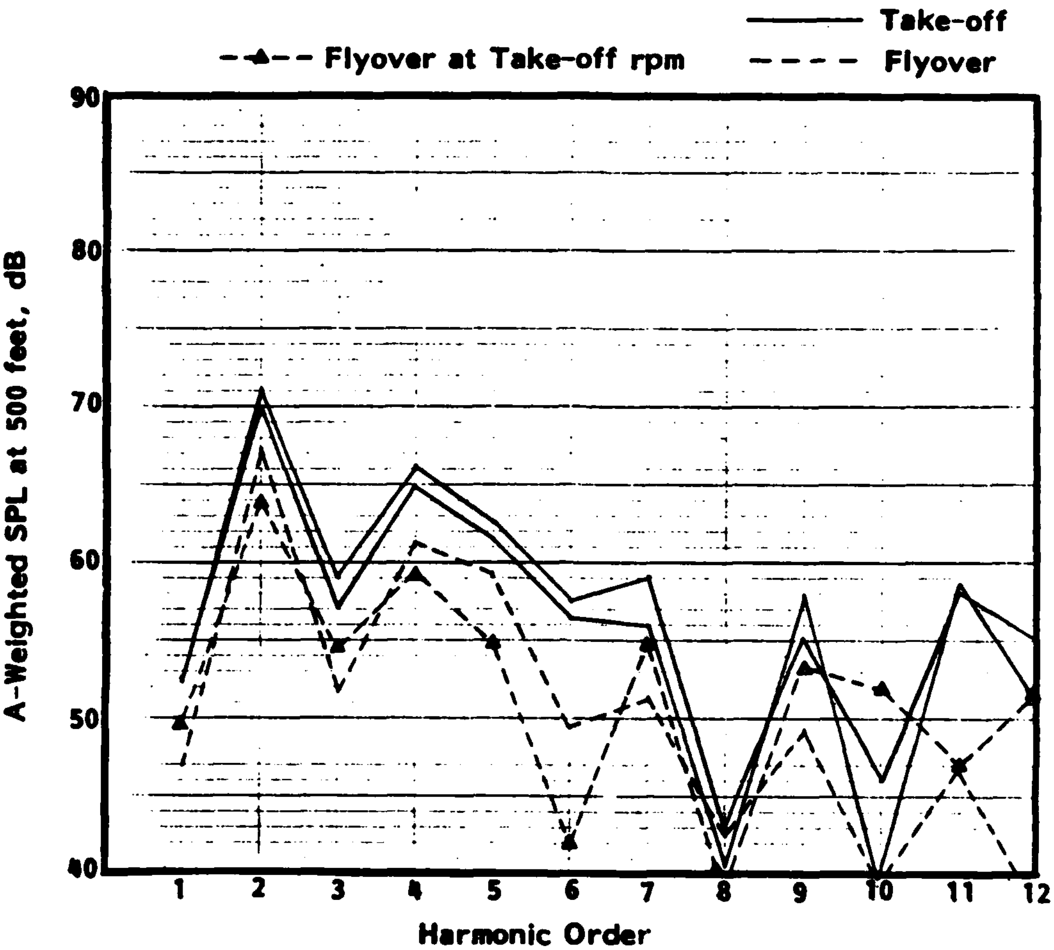


FIGURE D.8 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR PIPER PA-38-112 TOMAHAWK

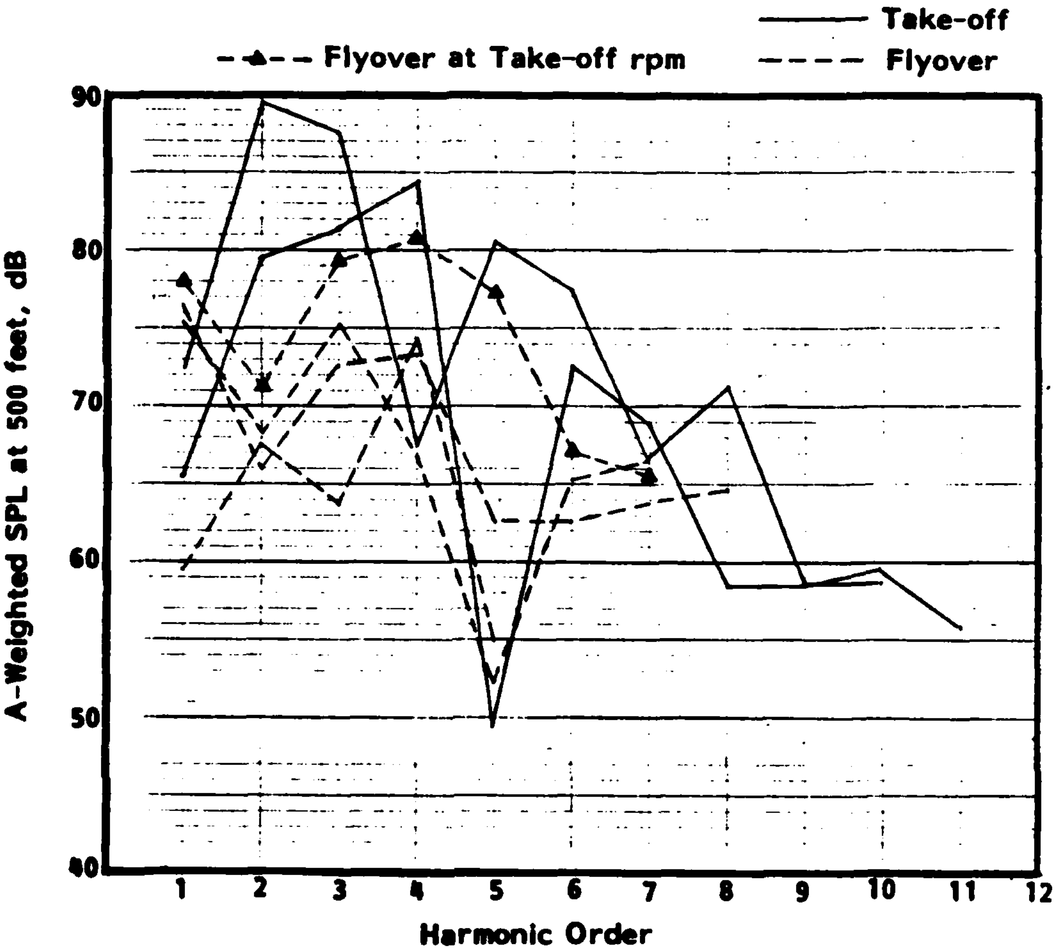


FIGURE D.9 MEASURED A-WEIGHTED SOUND LEVELS AT HARMONICS OF PROPELLER BLADE PASSAGE FREQUENCY FOR PIPER PA-42 CHEYENNE

APPENDIX E
A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA

APPENDIX E
A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA

A-weighted one-third octave band spectra were obtained by replaying the recorded signal into a Spectral Dynamics SD312-22 One-Third Octave Band Analyzer that was set to the A-weighting network (except when the signal was recorded on tape already A-weighted). An averaging time of 0.5 sec was used for the data reduction, and the averaging period was centered approximately on the time of maximum overall A-weighted sound level. This approach is similar to that used for the narrowband spectrum analysis presented in Appendix B. However, the narrowband and one-third octave band analyses were performed independently and the two integration or averaging time periods may not be identical. Thus, some small differences in spectrum level may arise, particularly when the A-weighted sound level varies rapidly with time.

The one-third octave band spectra associated with a microphone height of 4 feet are presented in Figures E.1 through E.16 for the eight test airplanes. The spectra present data for one-third octave bands with center frequencies to 20,000 Hz; the sound level shown in the figures at 25,000 Hz is actually the overall A-weighted sound level for the data sample.

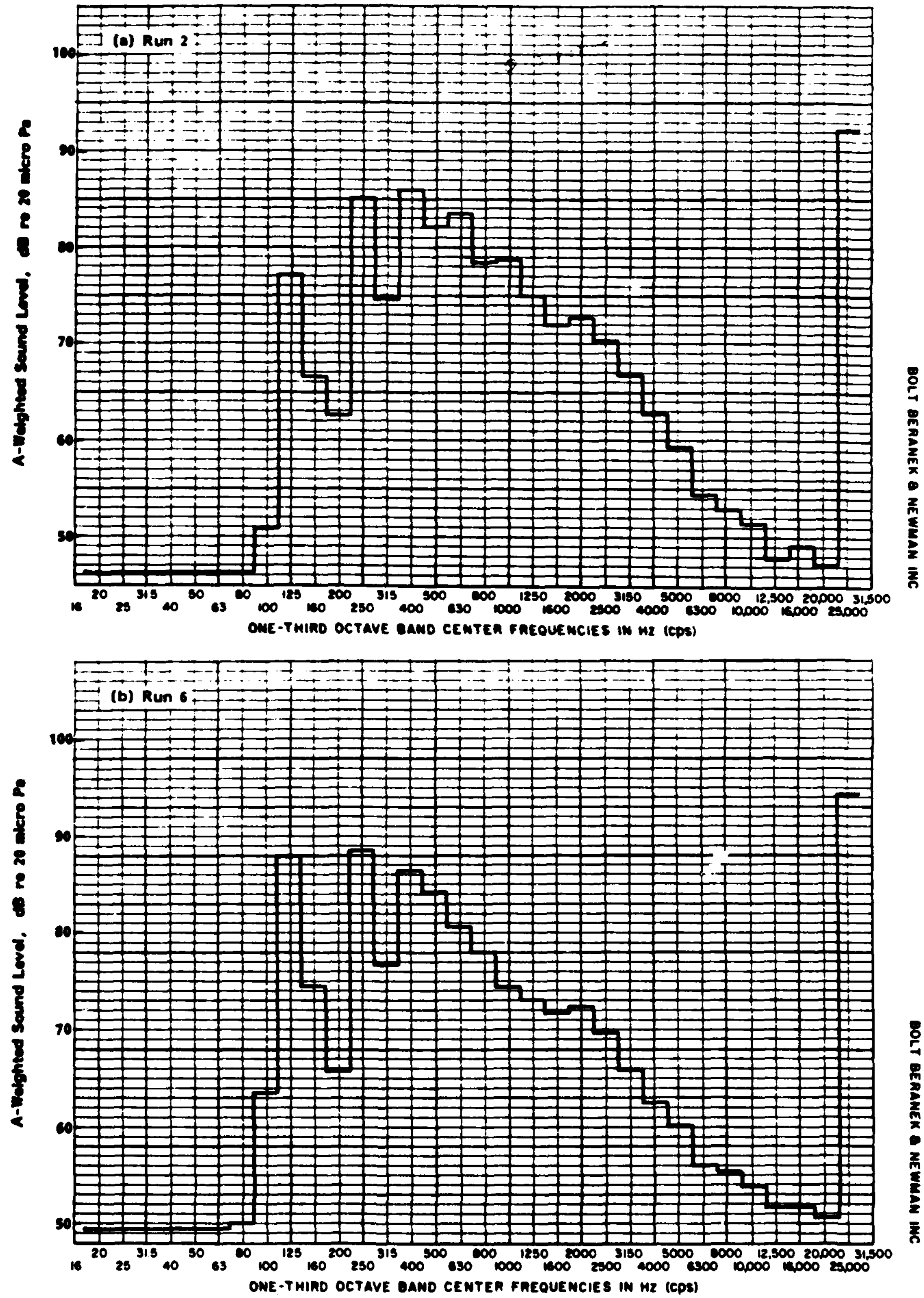


FIGURE E.1 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF BEECH B58P BARON

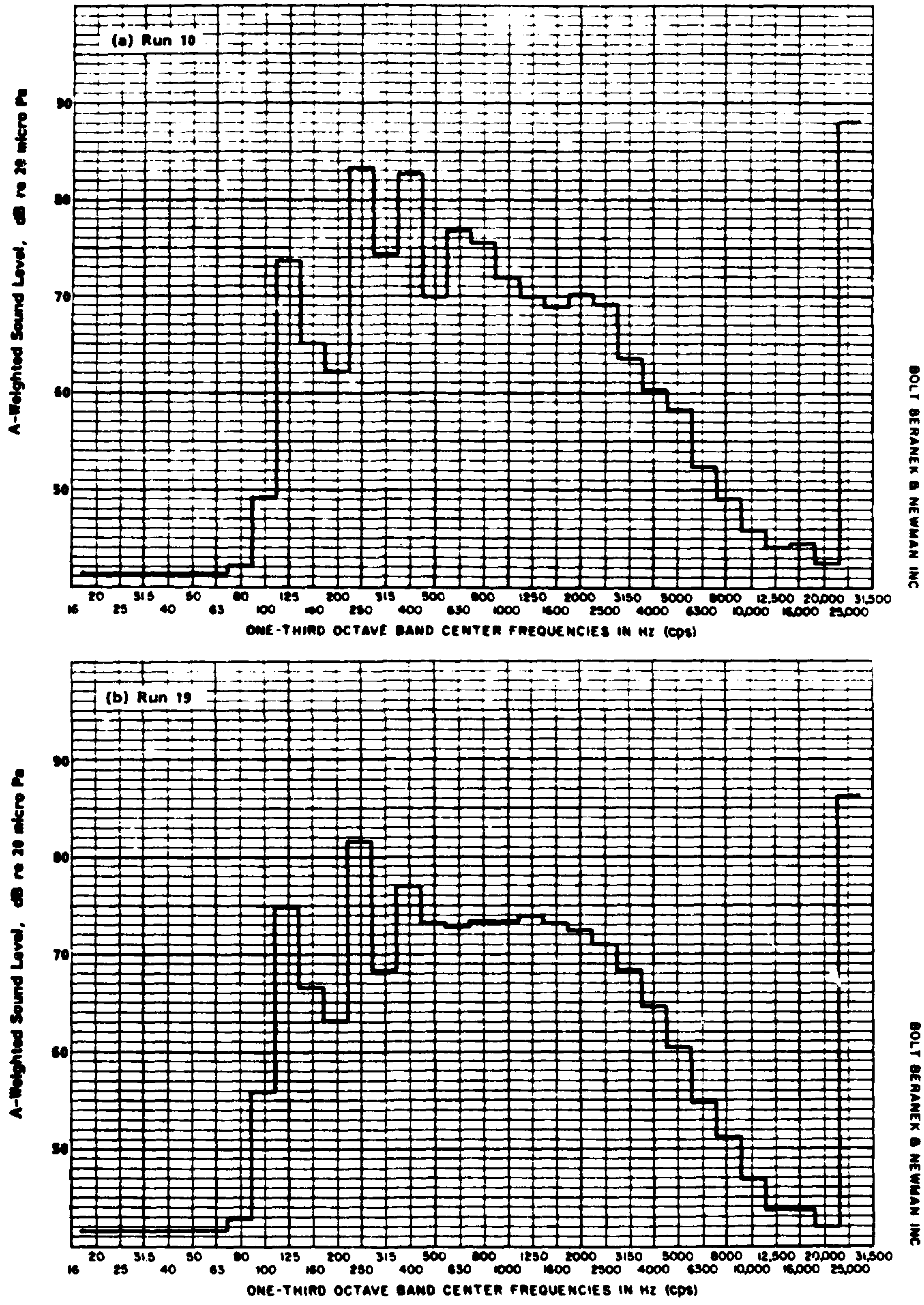


FIGURE E.2 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF BEECH B58P BARON

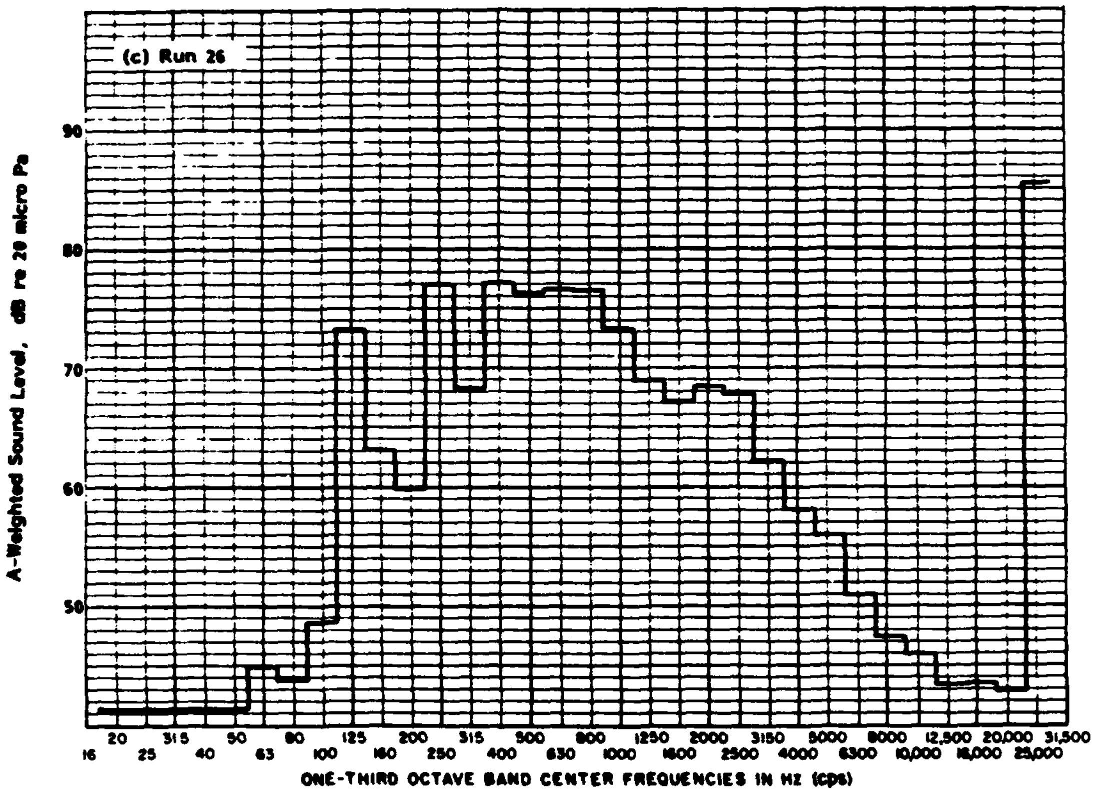


FIGURE E.2 CONTINUED

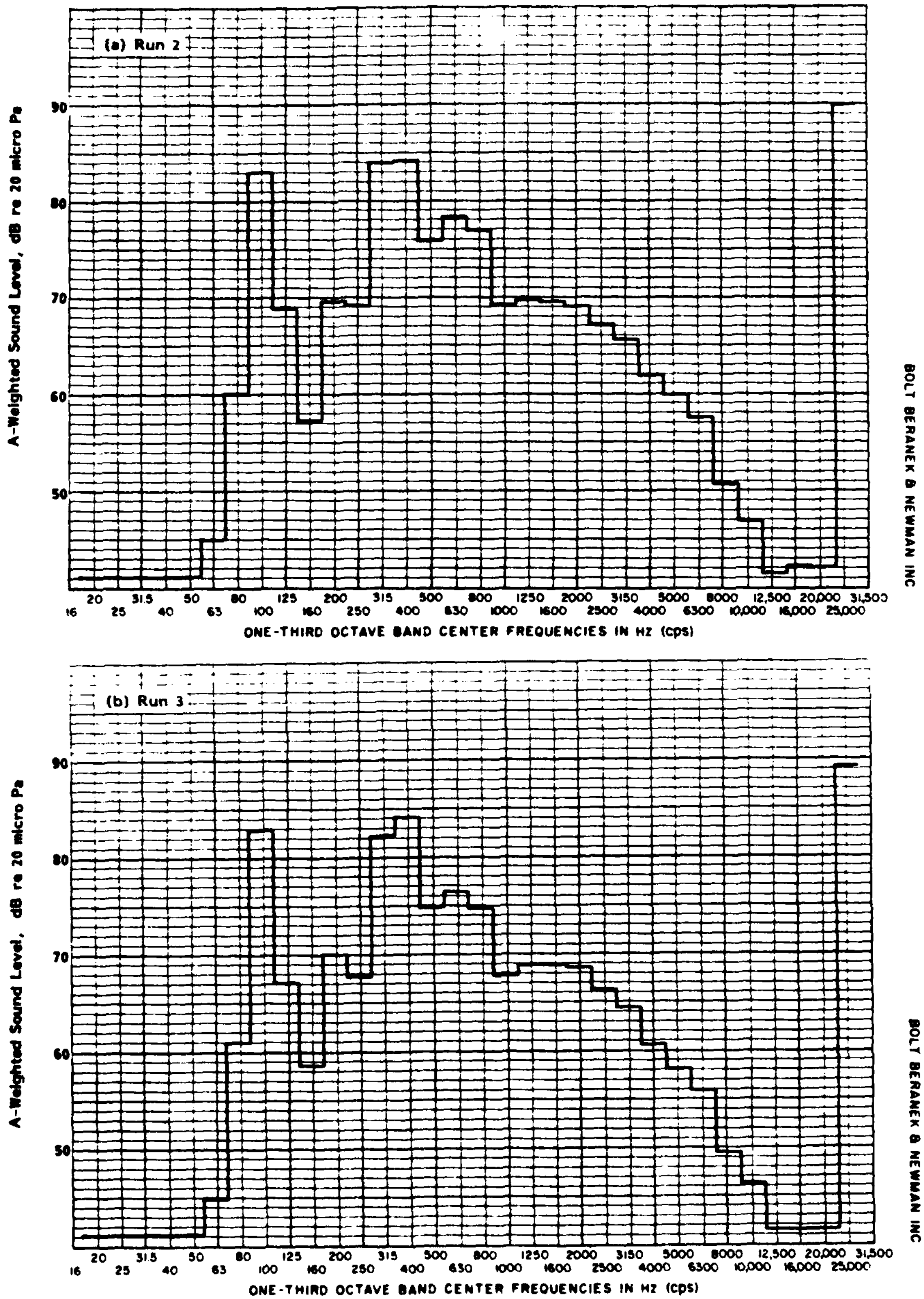


FIGURE E.3 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF BEECH B200 SUPER KING AIR

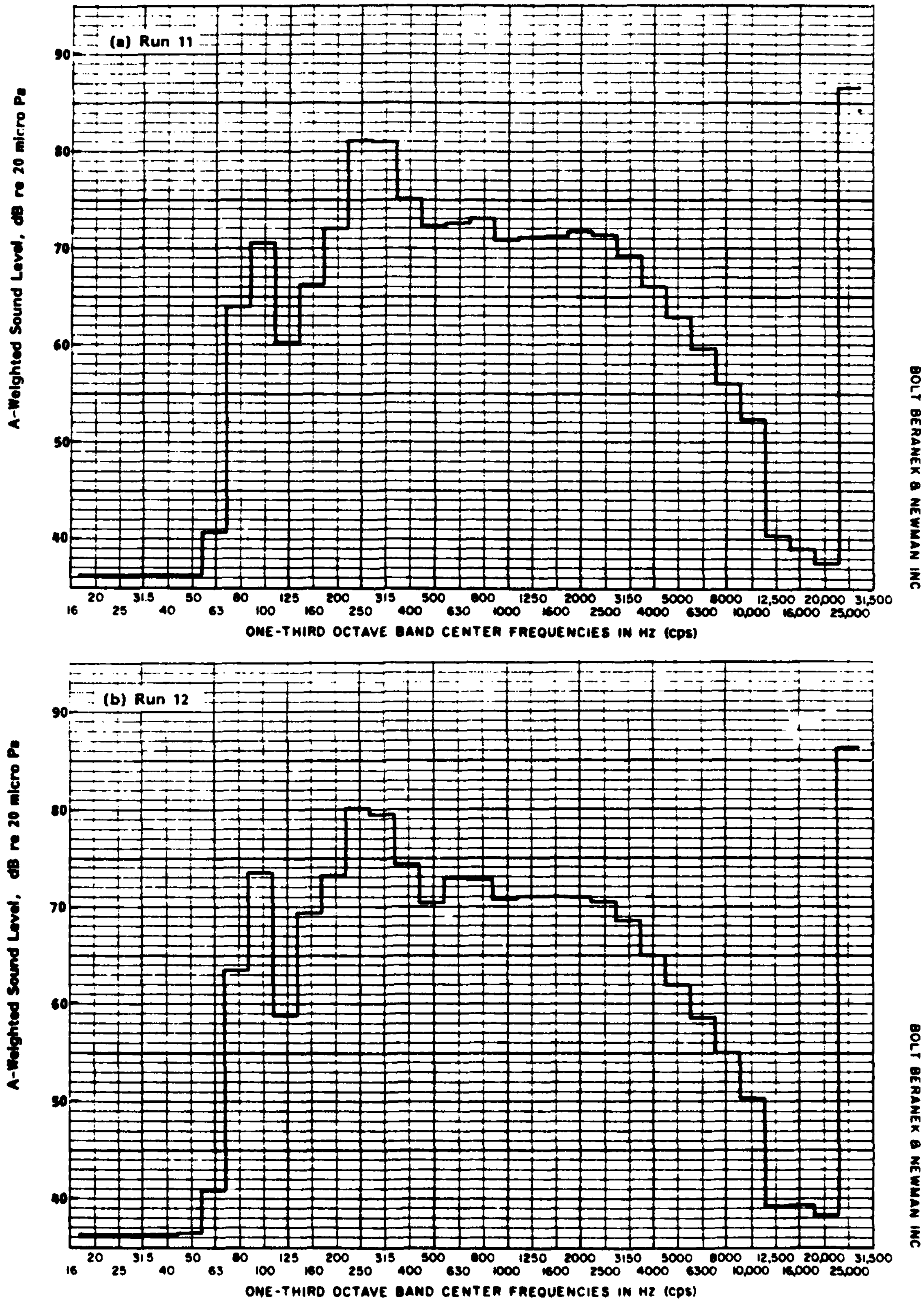
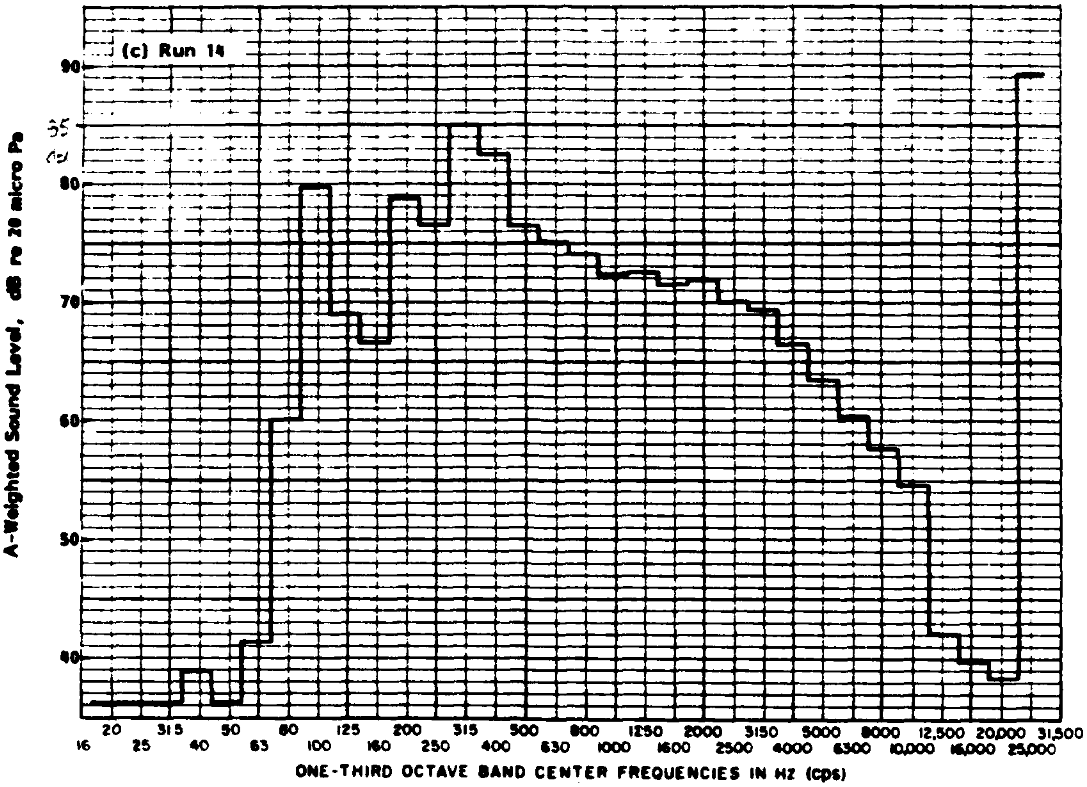


FIGURE E.4 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF BEECH B200 SUPER KING AIR



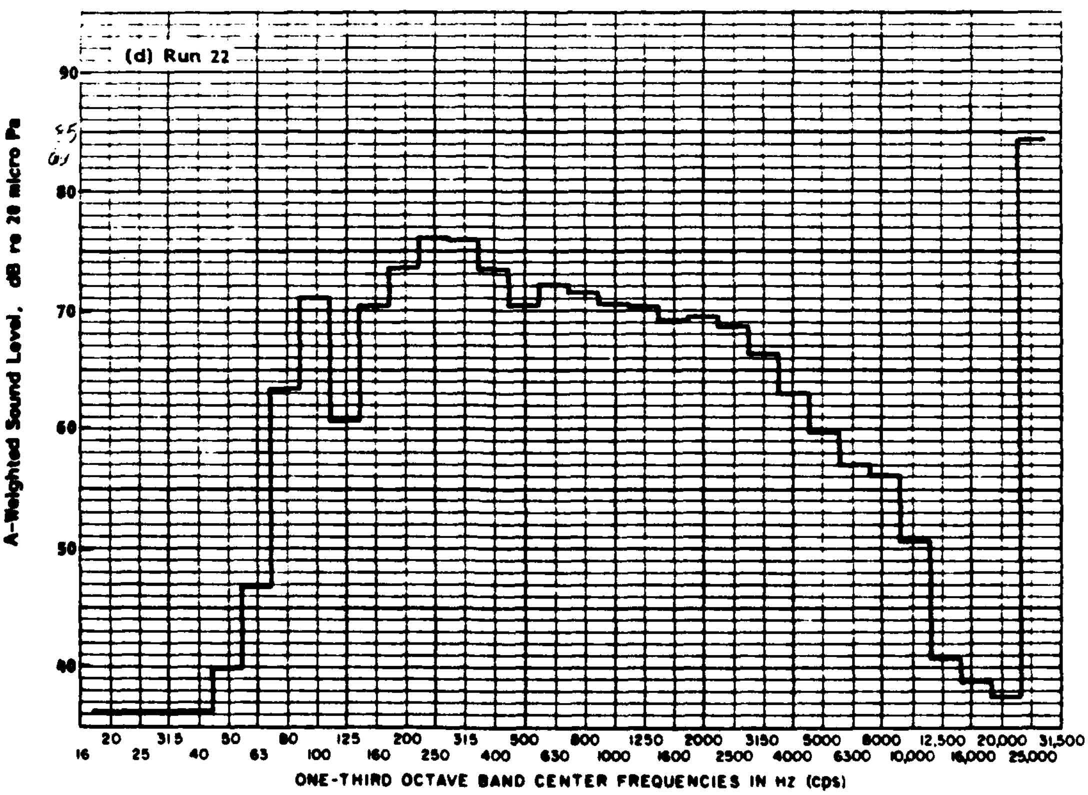


FIGURE E.4 CONTINUED

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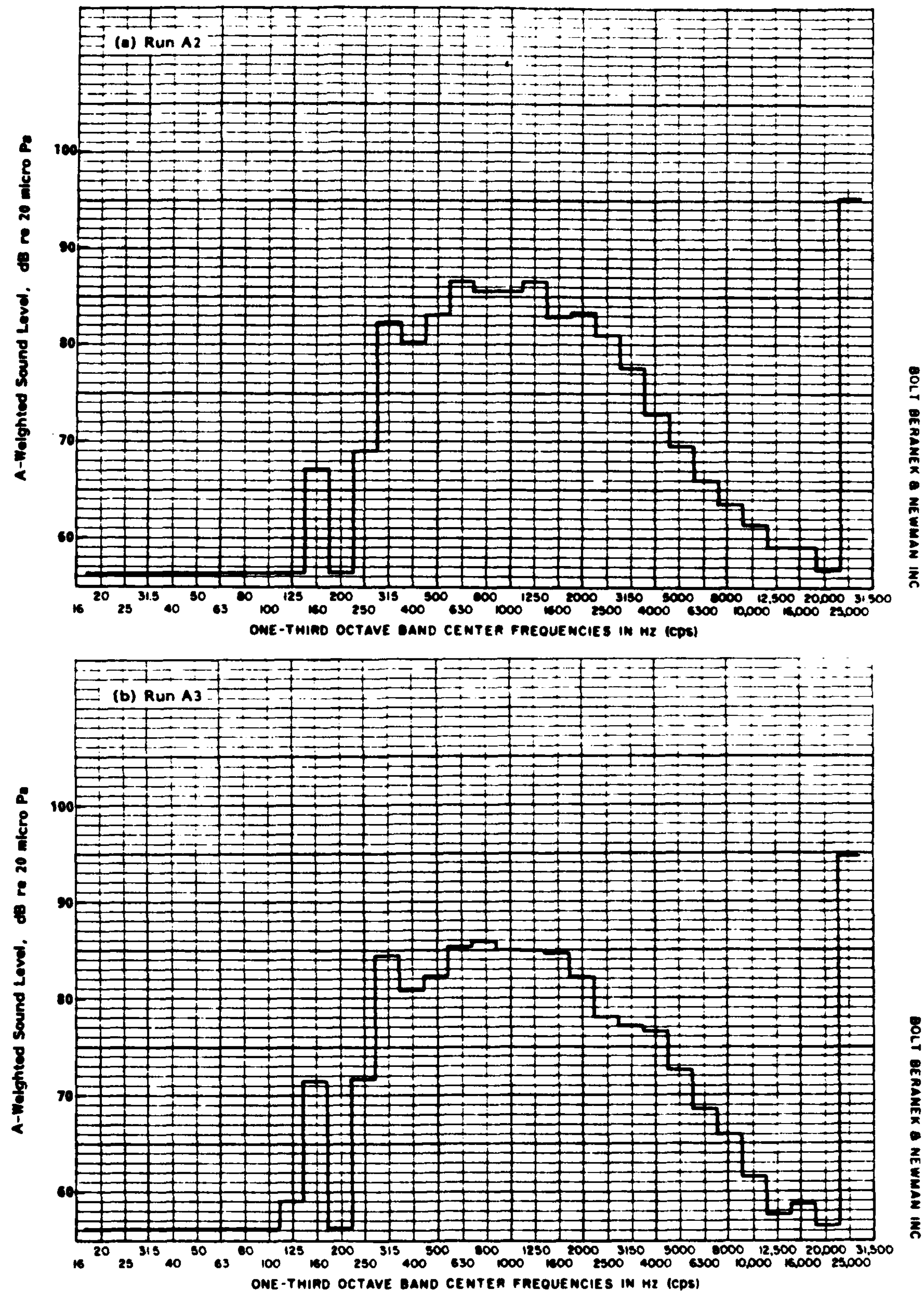
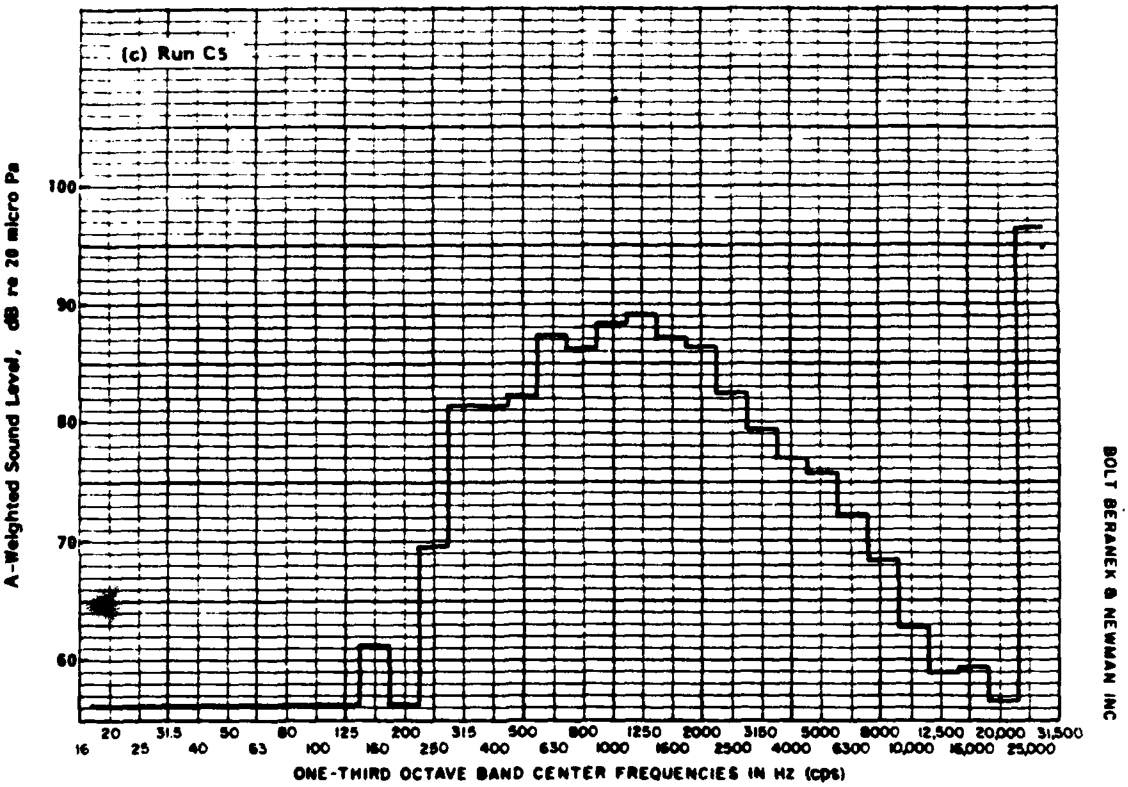


FIGURE E.5 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKEOFF OF CESSNA 210 CENTURION



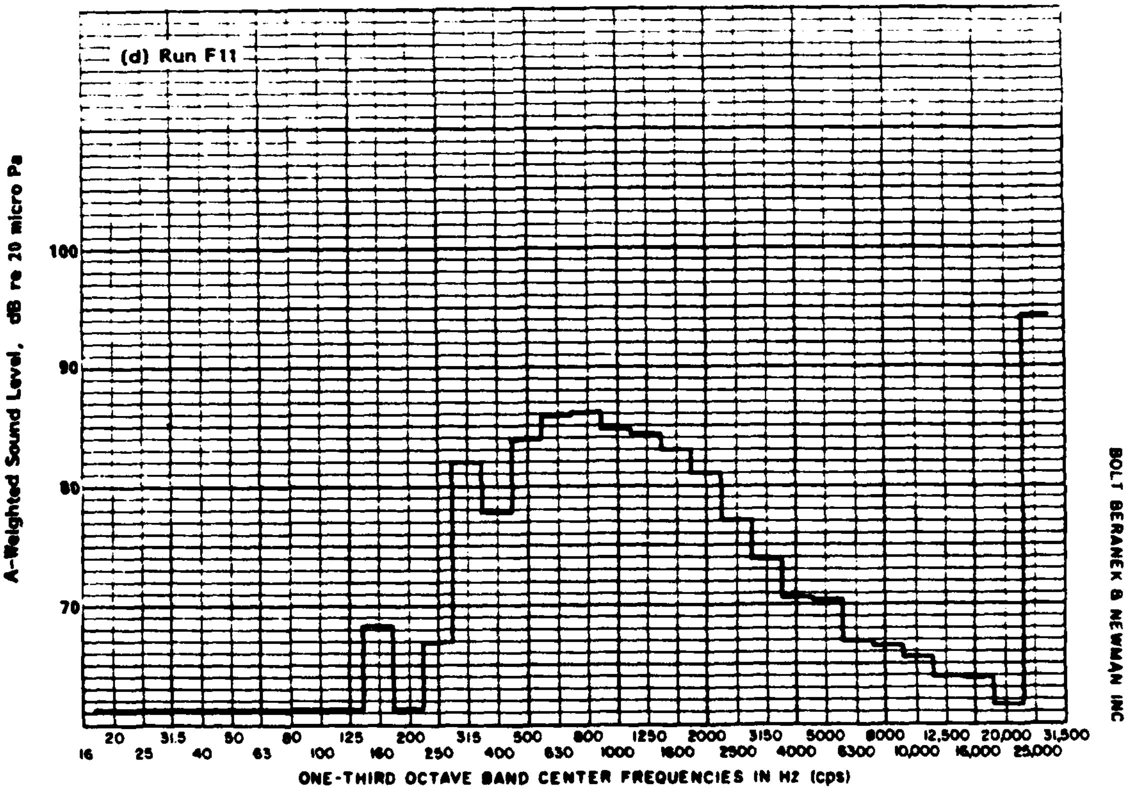


FIGURE E.5 CONTINUED

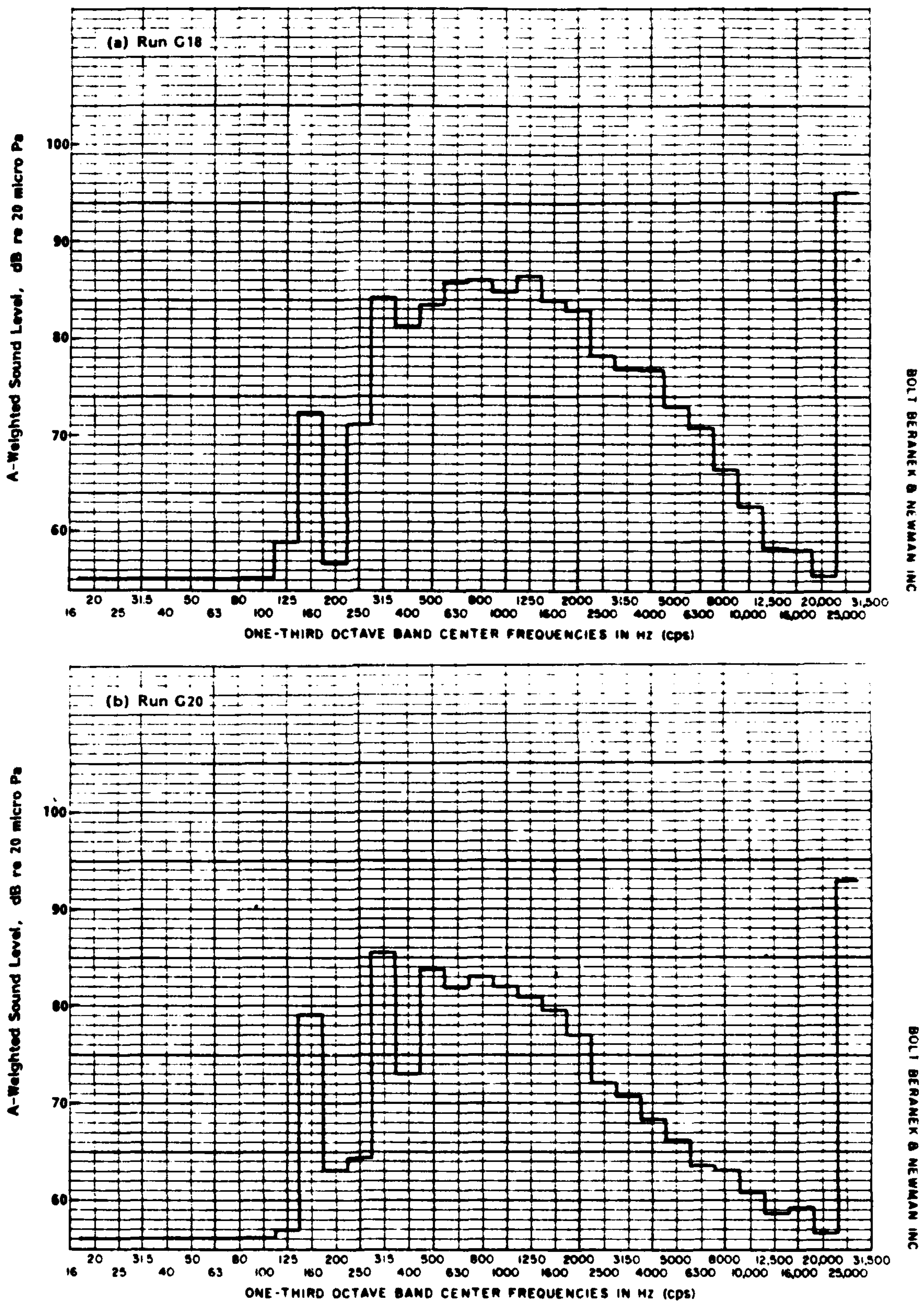


FIGURE E.6 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF CESSNA 210 CENTURION

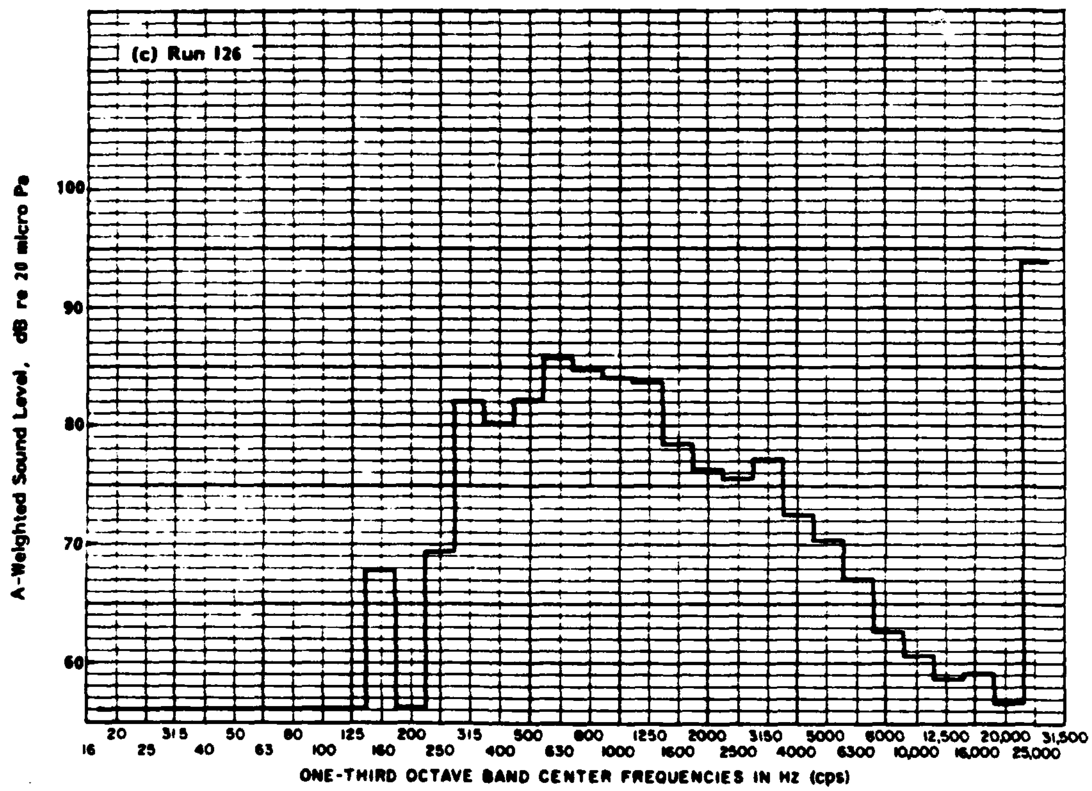


FIGURE E.6 CONTINUED

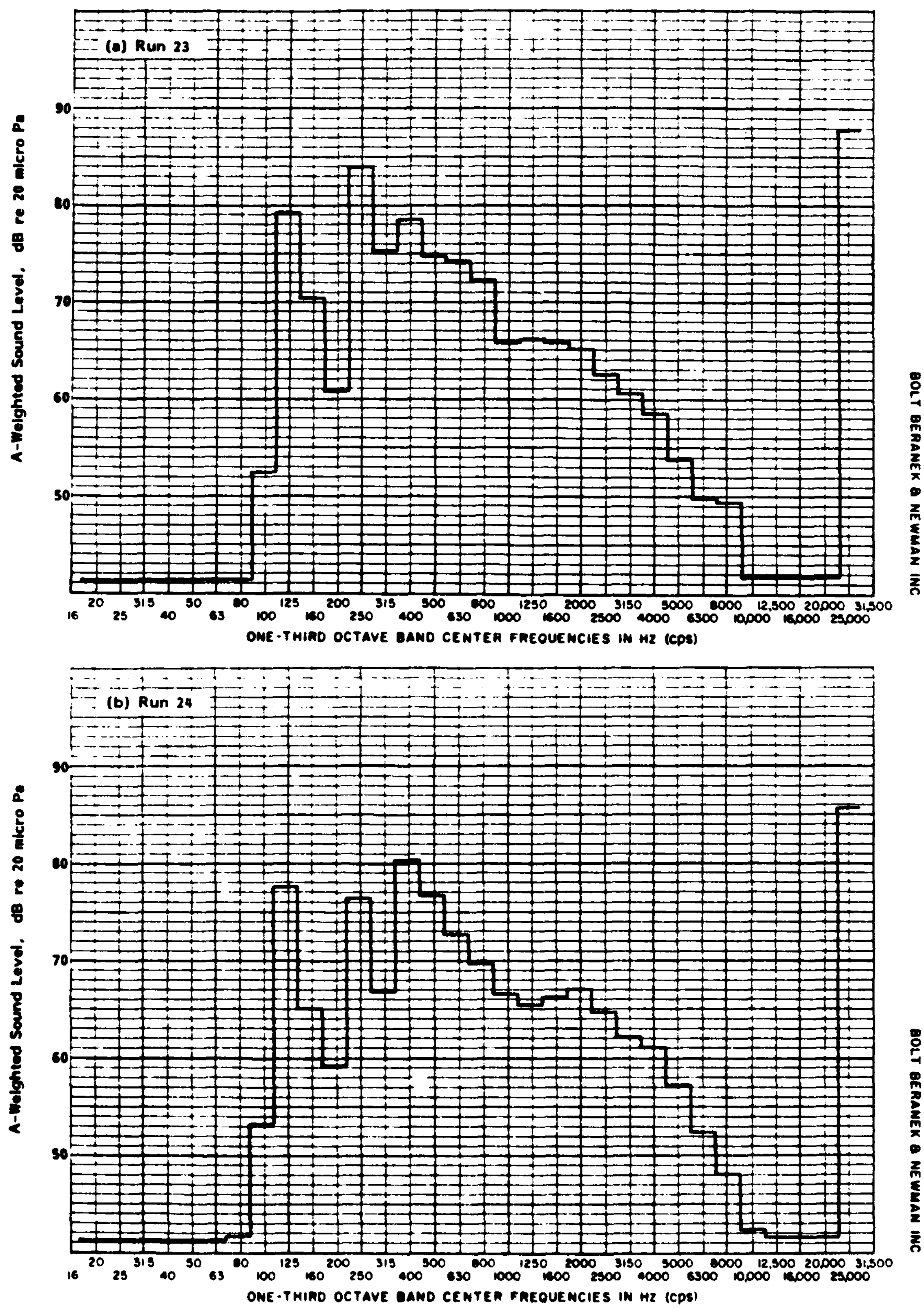


FIGURE E.7 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF CESSNA 414 CHANCELLOR

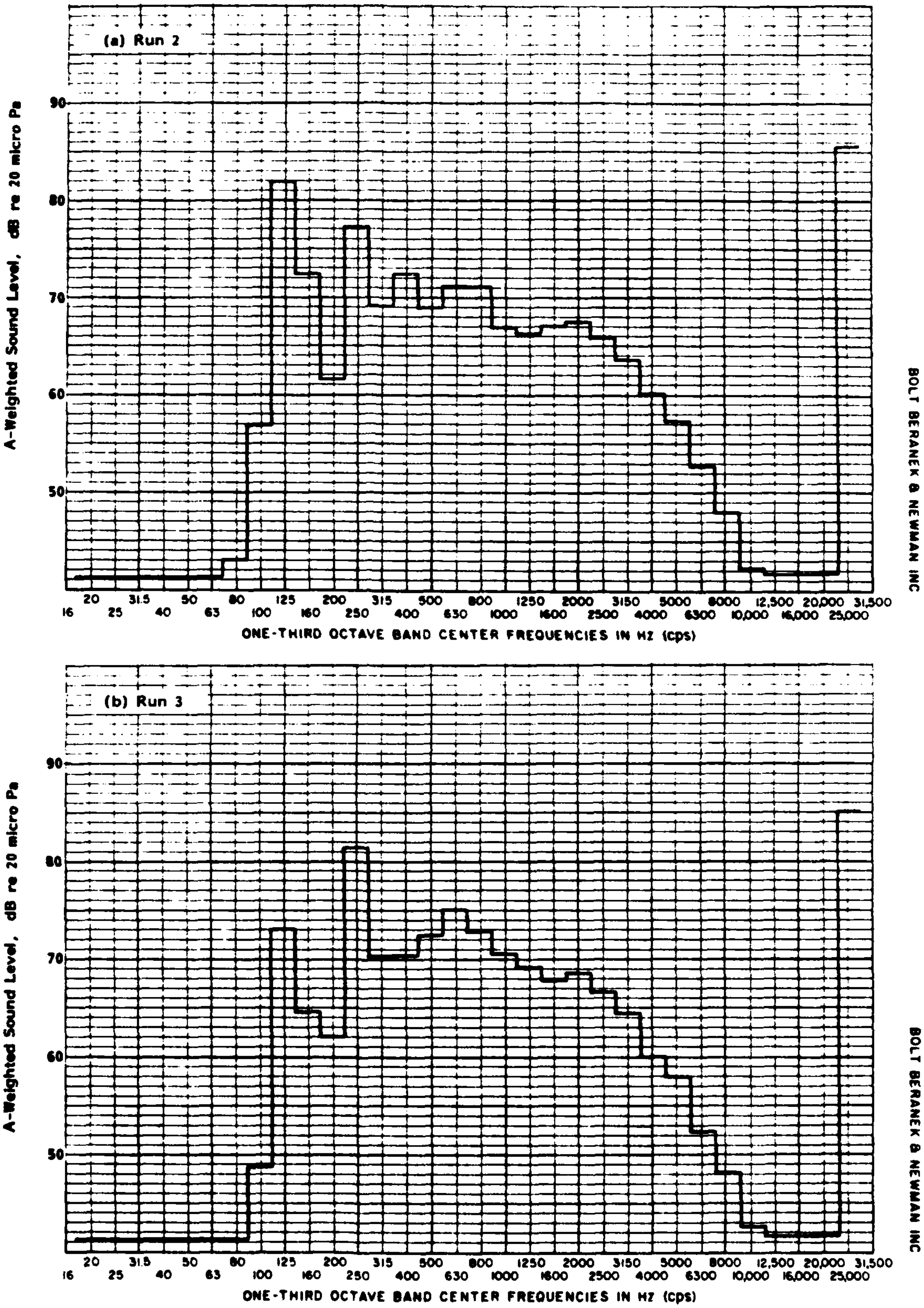


FIGURE E.8 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF CESSNA 414 CHANCELLOR

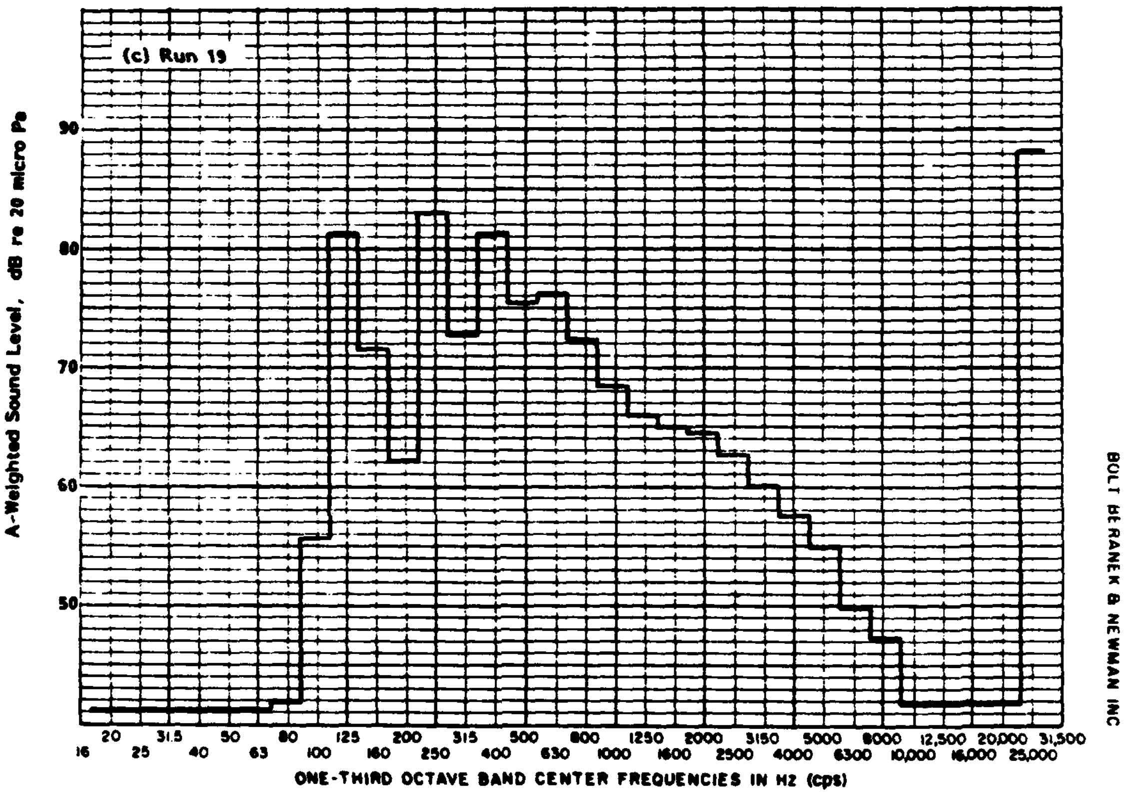
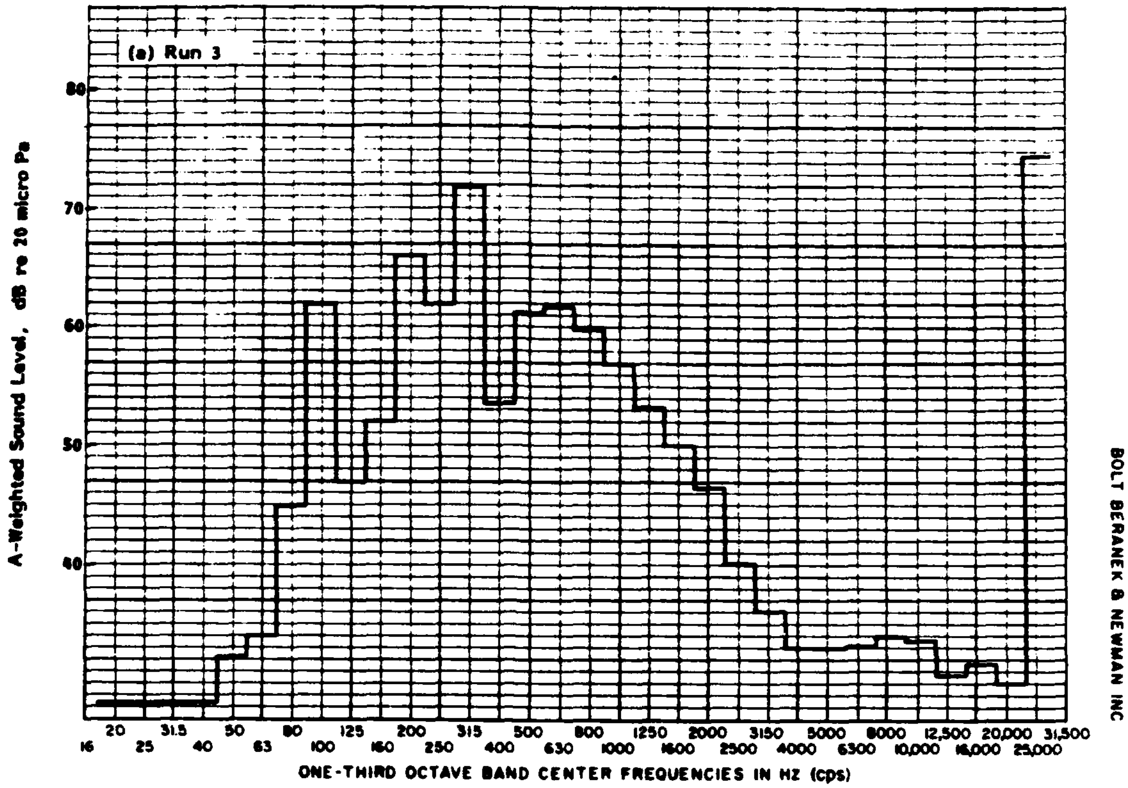


FIGURE E.8 CONTINUED



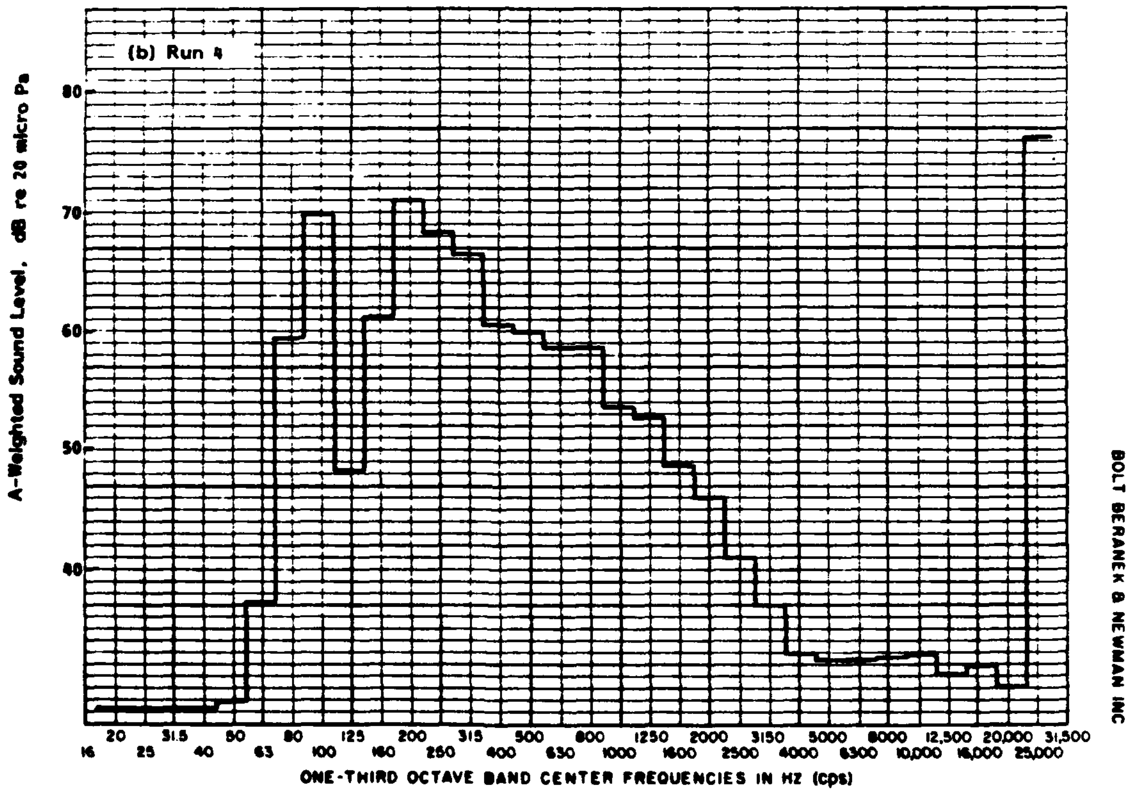


FIGURE E.9 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF CESSNA 425 CONQUEST 1

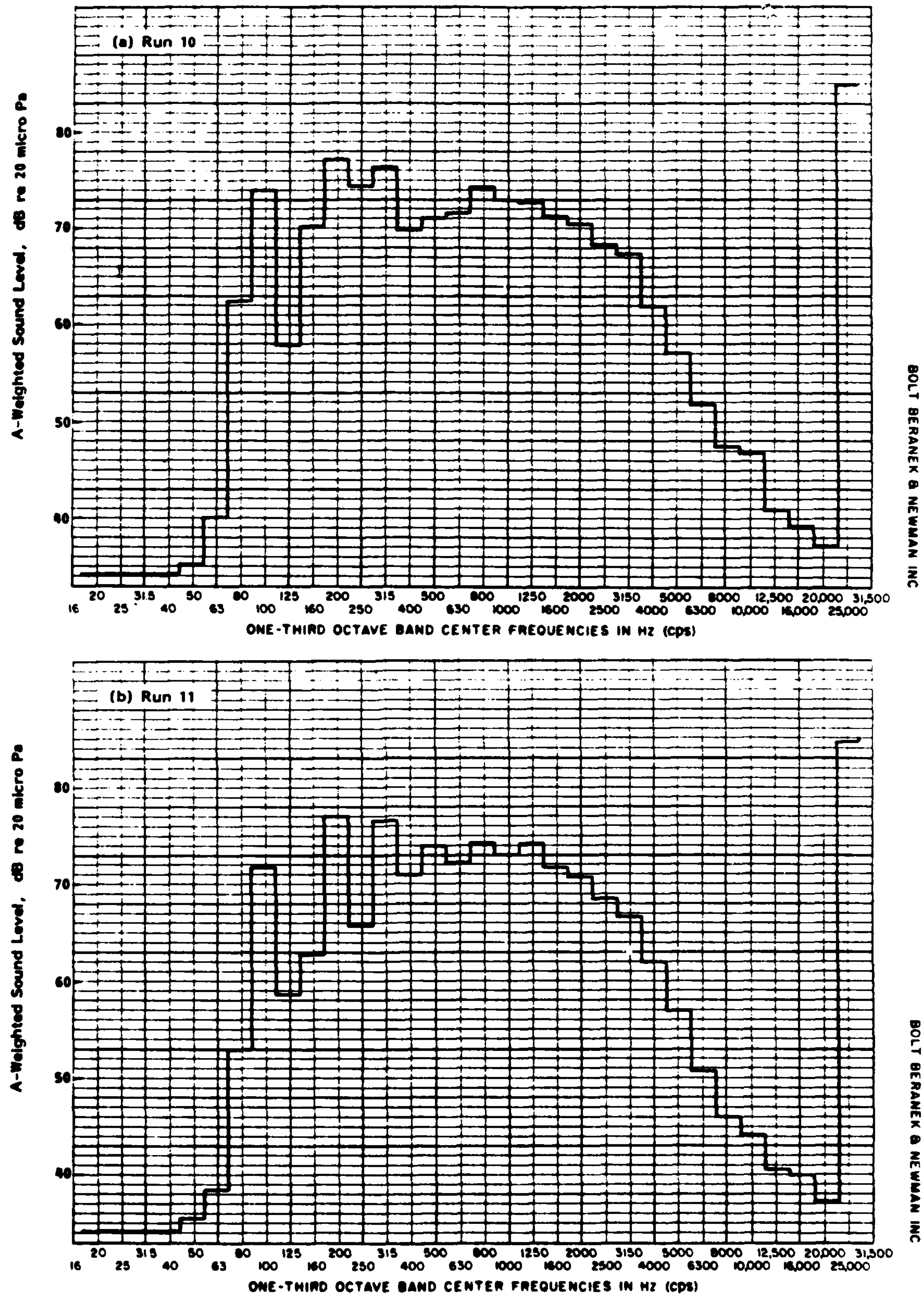
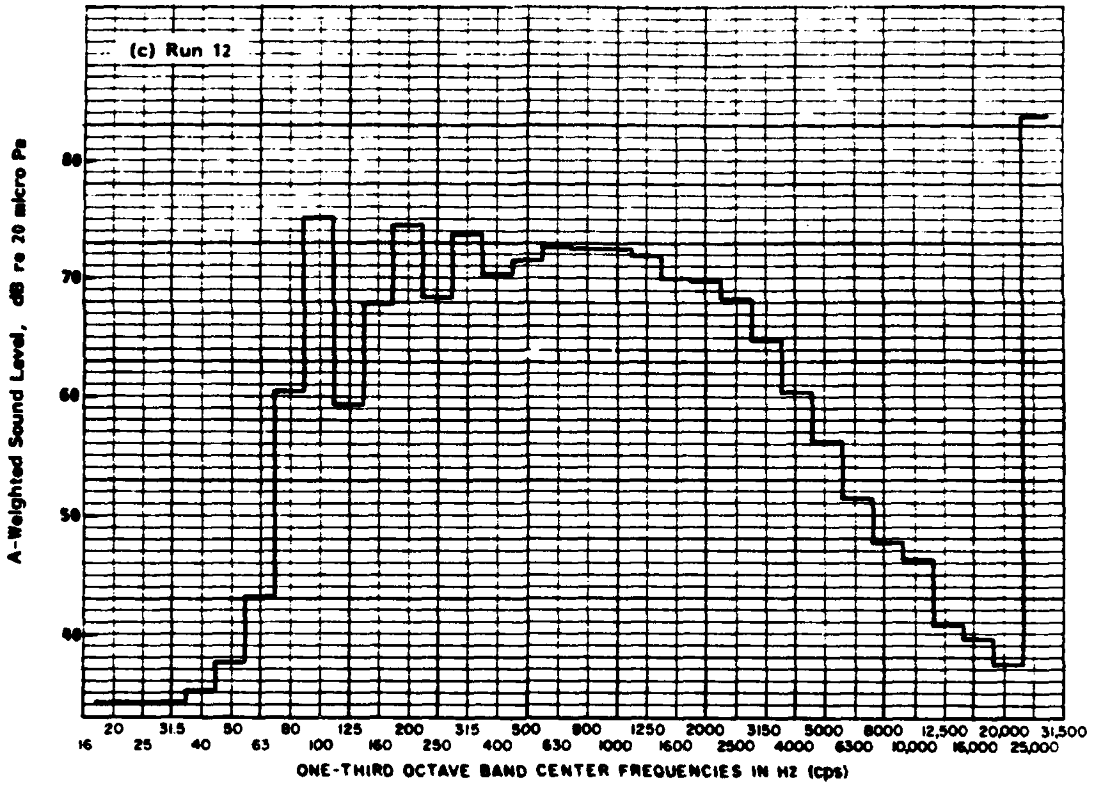


FIGURE E.10 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF CESSNA 425 CONQUEST 1



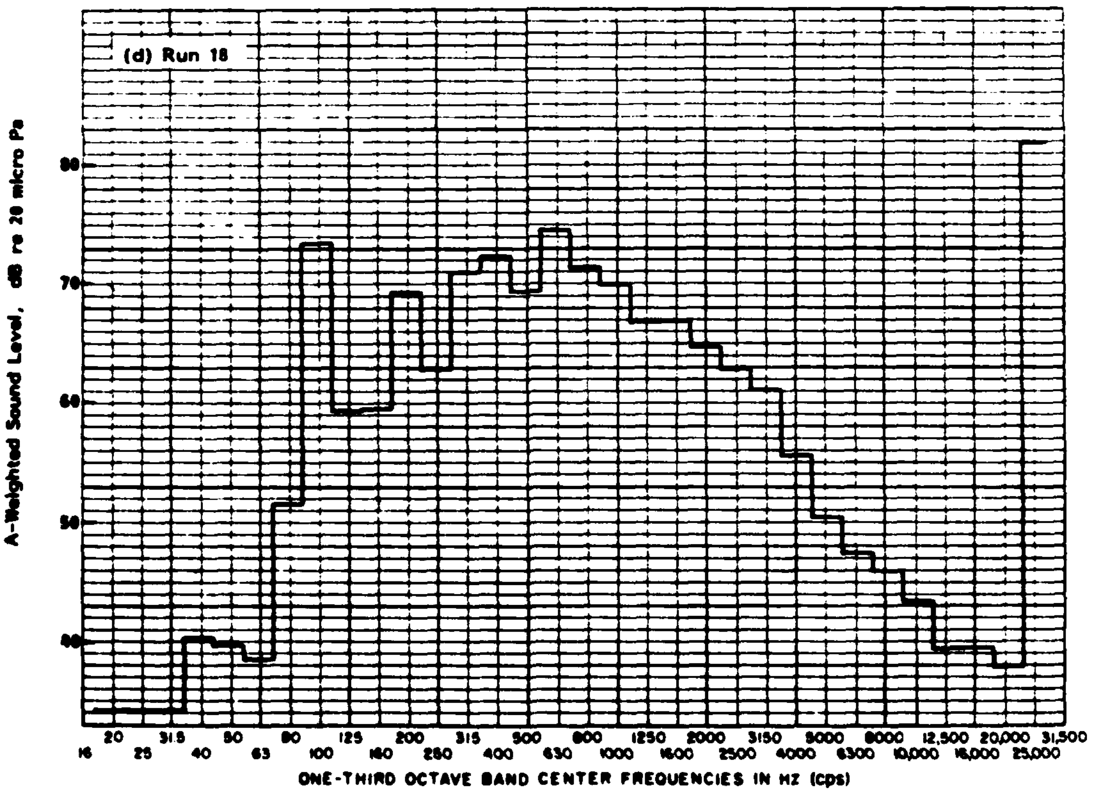


FIGURE E.10 CONTINUED

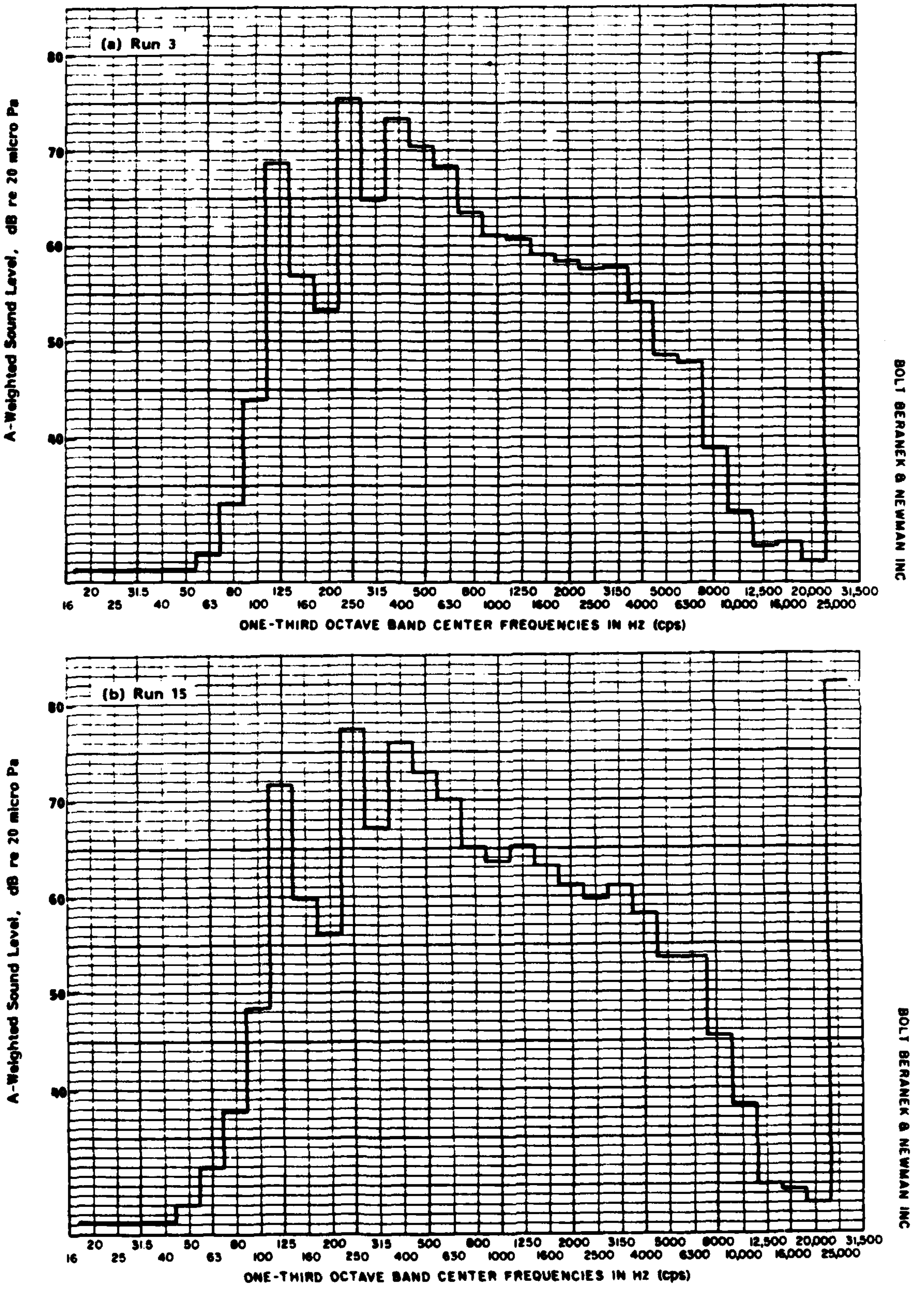


FIGURE E.11 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF PIPER PA-28RT-210T TURBO ARROW IV

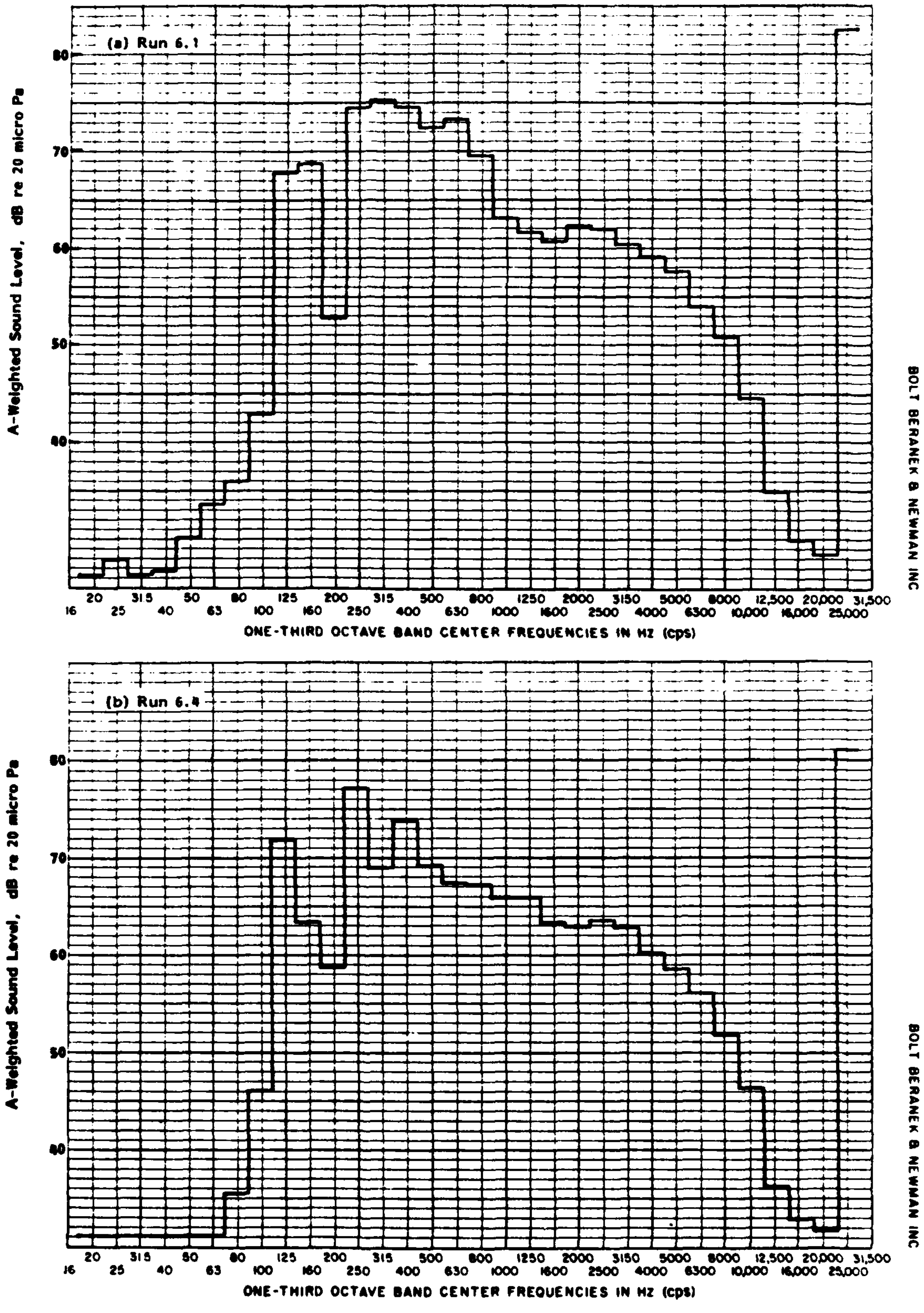


FIGURE E.12 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF PIPER PA-28RT-210T TURBO ARROW IV

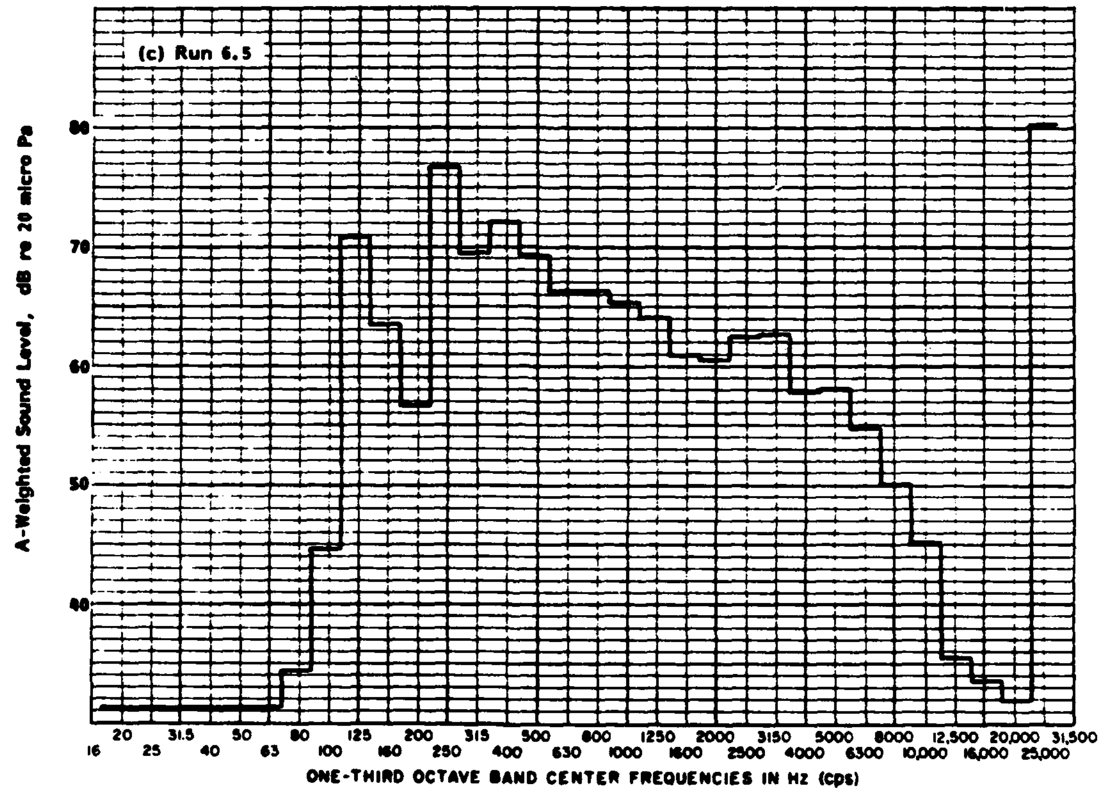
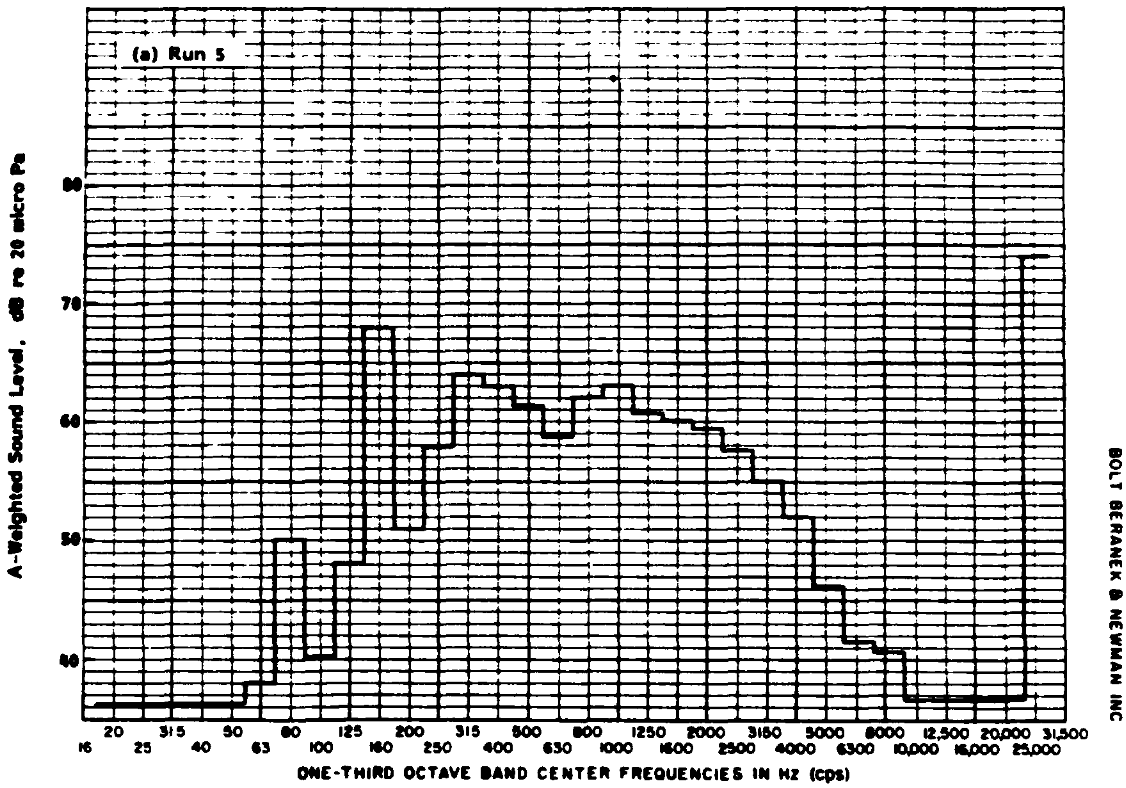


FIGURE E. 12 CONTINUED



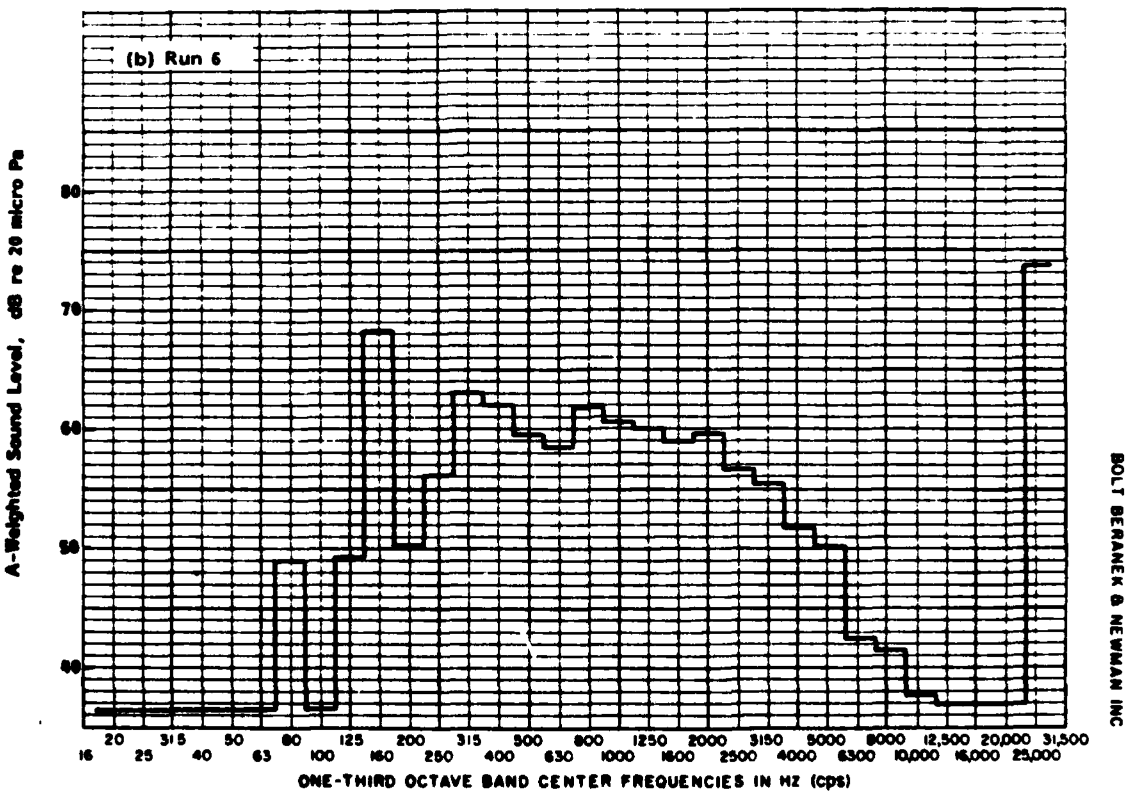
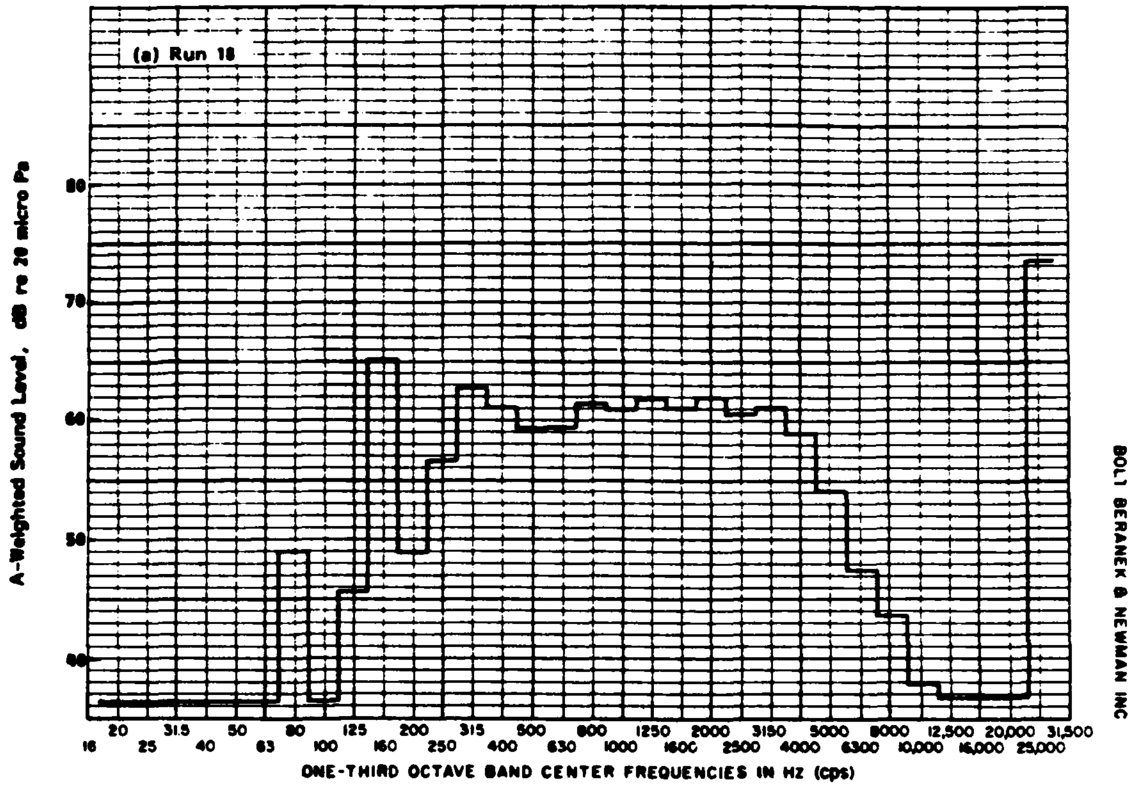


FIGURE E.13 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF PIPER PA-38-112 TOMAHAWK



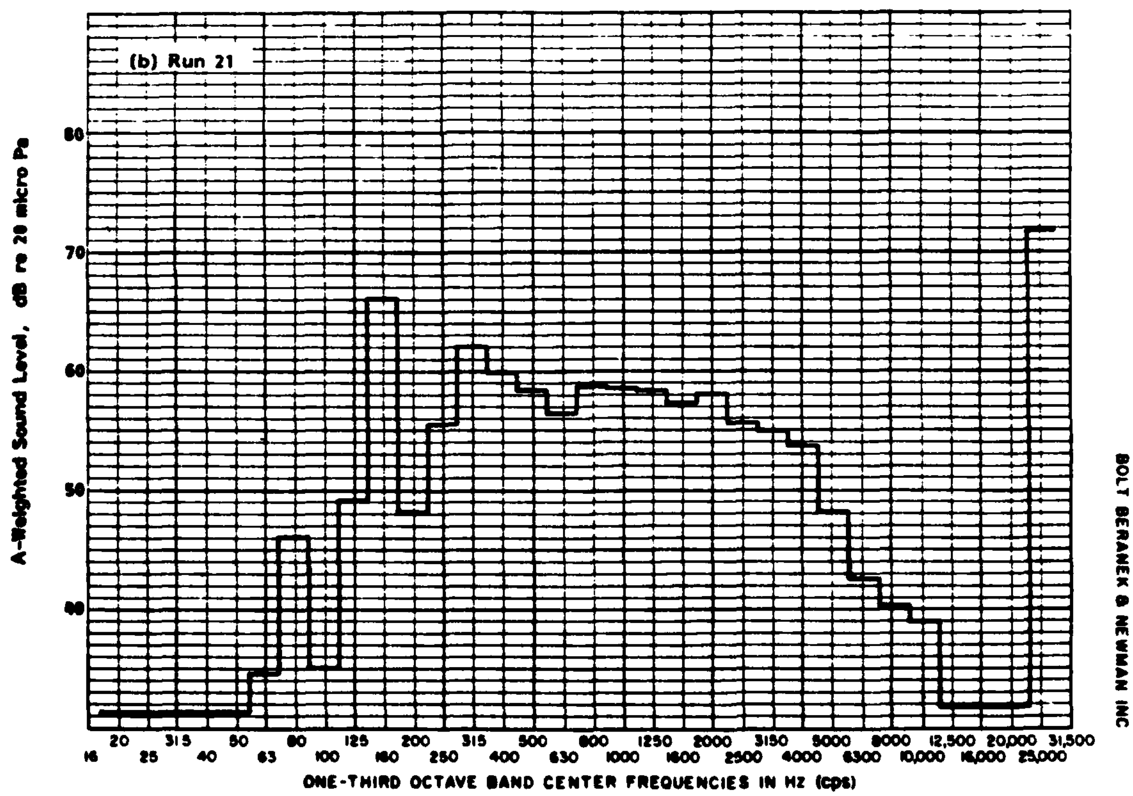
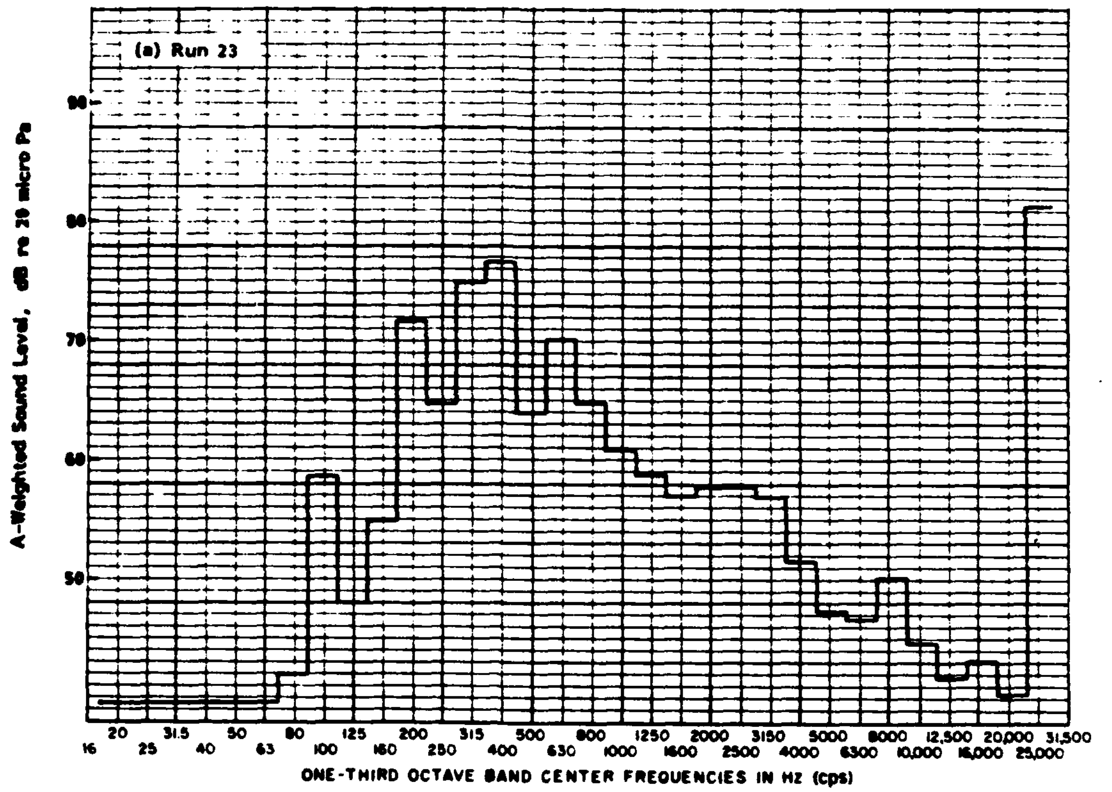


FIGURE E.14 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF PIPER PA-38-112 TOMAHAWK



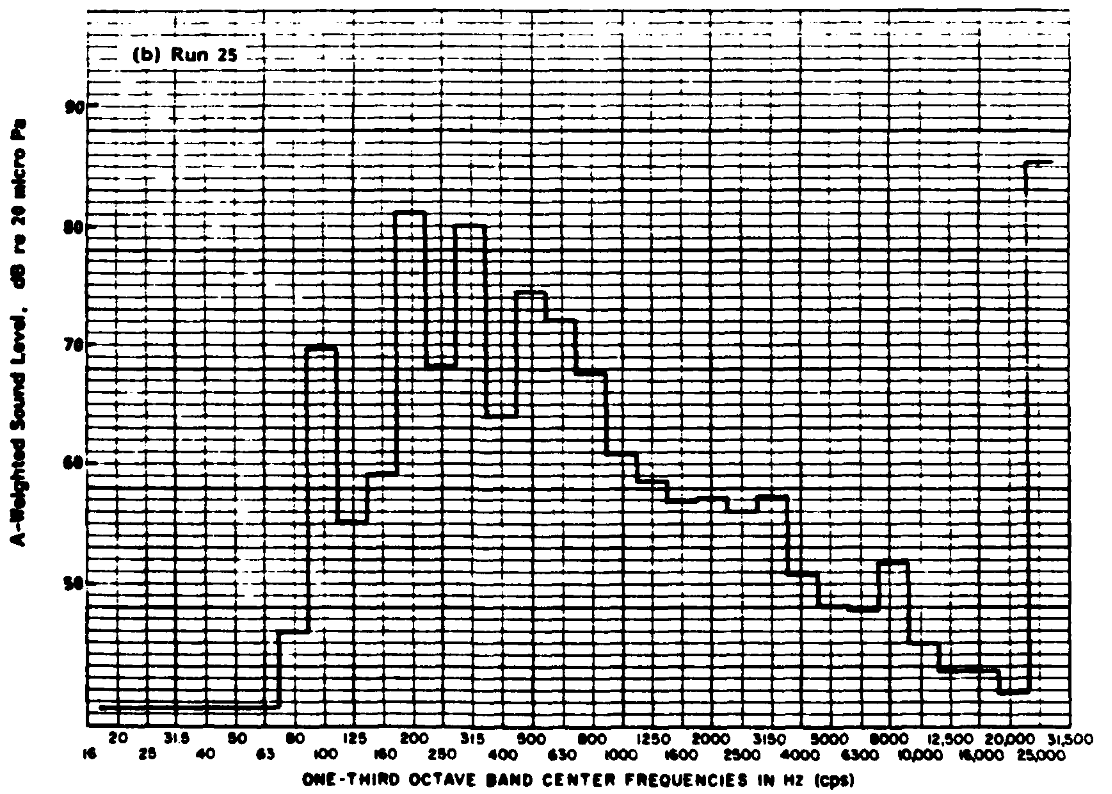


FIGURE E.15 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR TAKE-OFF OF PIPER PA-42 CHEYENNE

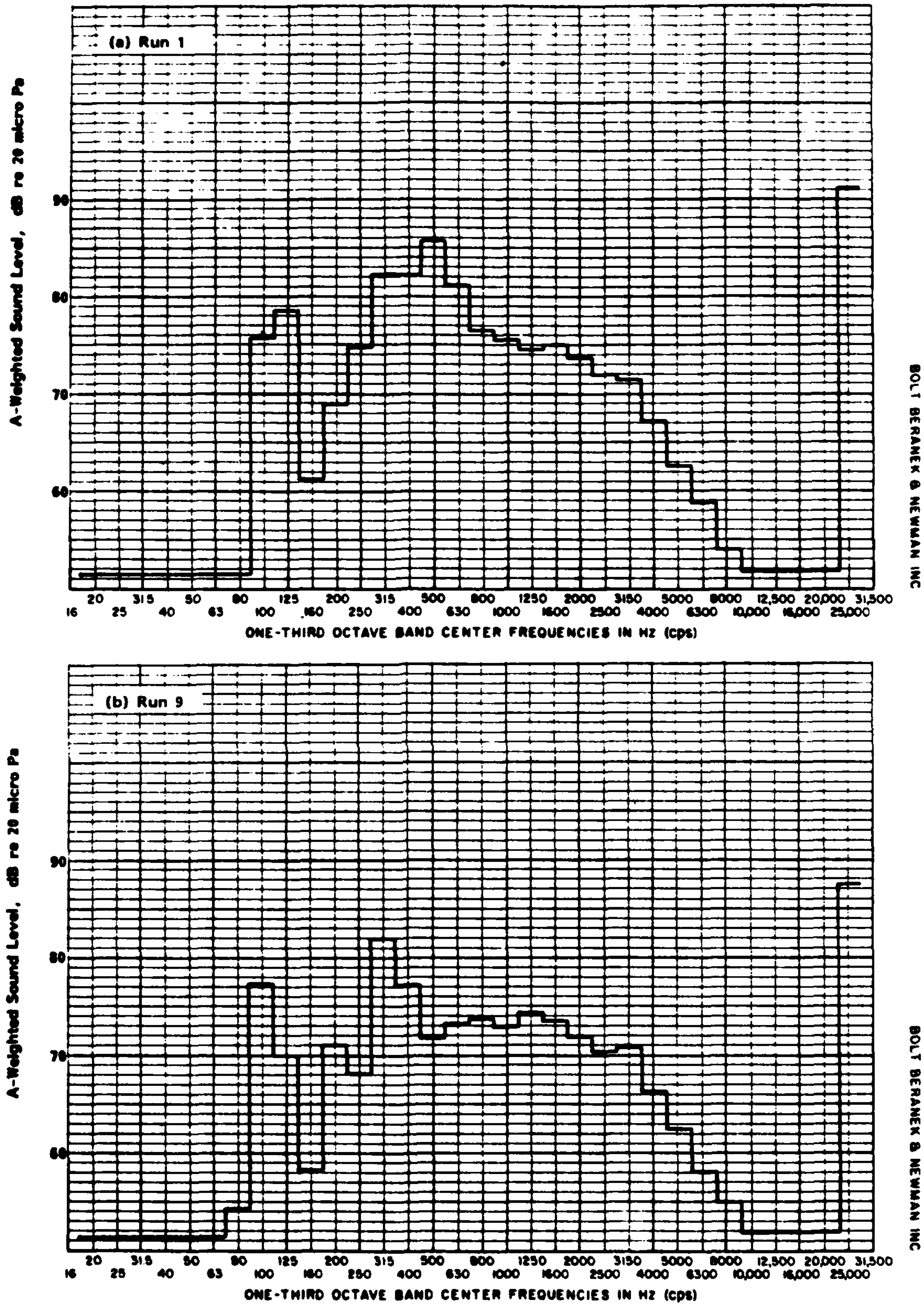
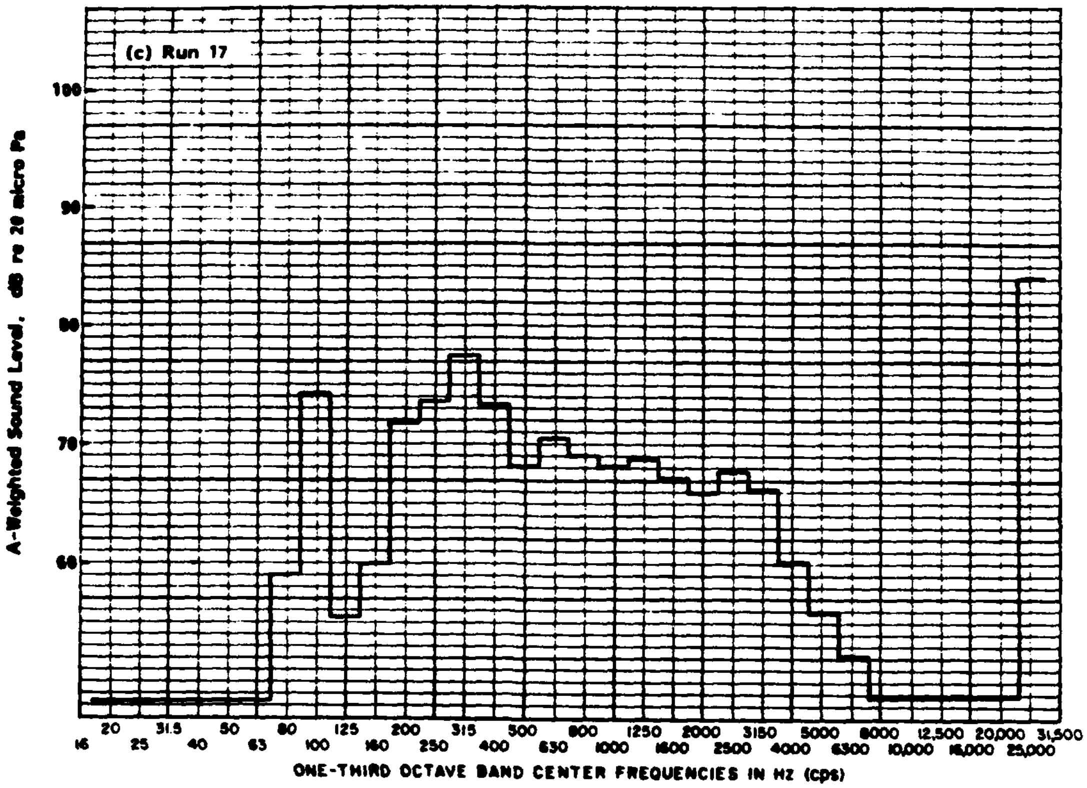


FIGURE E.16 A-WEIGHTED ONE-THIRD OCTAVE BAND SPECTRA FOR FLYOVER OF PIPER PA-42 CHEYENNE



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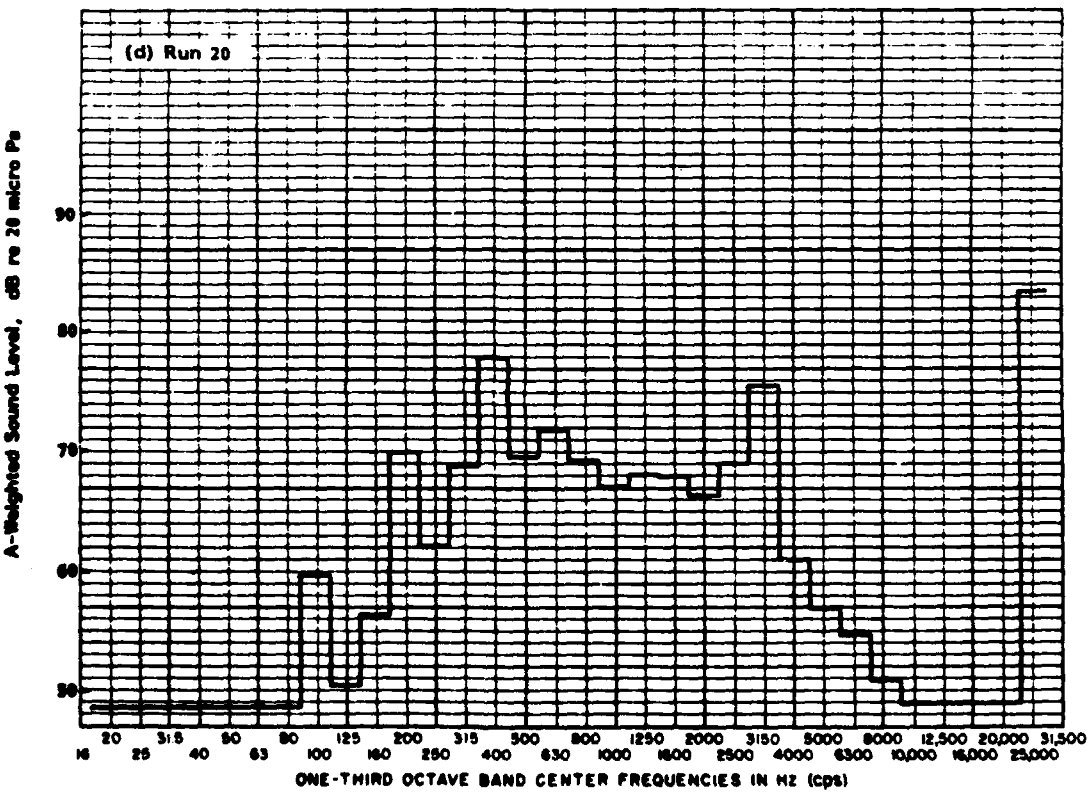

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FIGURE E.16 CONTINUED

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